The Influence of Retrieval Strategies on Event-Related Potential Correlates of Recognition Memory

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ABSTRACT

Scalp-recorded ERPs were employed in four experiments to explore the strategic control of recollection in a recognition exclusion task. For each experiment, the study phase comprised two study lists. The test required the endorsement of 'targets' from study list 2 and the rejection of 'non-targets' from study list 1 and 'new' items. Experiments 1-3 showed that the ERP signature for recollection, the 'left parietal old/new effect', was elicited by correctly rejected non-targets only when memory for targets was poor (cf. Herron & Rugg, 2003a). These findings support the proposal that, when there is good memory for targets, the adoption of a 'retrieval orientation' allows test cues to selectively probe memory for target source information. However, when target and non-target study tasks were identical (Experiment 4), left parietal effects were additionally found for non-targets despite high target accuracy. This indicates that the degree of similarity between target and non-target study contexts moderates the extent to which it is possible to focus retrieval attempts exclusively on target memories. However, when target and non-target study contexts were *partially* distinct (Experiment 4), a late posterior negativity was seen to attenuate an emerging left parietal effect for non-targets suggesting that non-target recollection was not completely precluded in this condition. Furthermore, the magnitude of the late posterior negativity was observed to correlate with the amount of contextual information associated with each item type that was *irrelevant* to the task demands. It was proposed that this negativity reflects processes acting upon a mismatch between the targeted memory representation and the contextual details that are actually retrieved. When such mismatches occur, an additional strategic control process, 'attentional suppression', may provide an account of how target memories can be successfully isolated from among competing alternatives.

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Contemporary research into memory processes delineates three main stages: encoding, storage and retrieval. An influential principle in memory research indicates that memory performance is a function of the degree to which cognitive operations engaged at encoding are recapitulated at retrieval ('transfer-appropriate processing': Morris, Bransford & Franks, 1977; 'encoding specificity': Tulving & Thomson, 1973). However, given that there is far more information in memory than can be accessed at any one point in time (Tulving & Pearlstone, 1966), it is important to consider how we can selectively retrieve some memories and not others. Furthermore, while some memories may be quite distinct, other memories may share many overlapping features. This highlights the critical role of control processes in constraining and selecting specific memories among many competing alternatives.

The experiments presented in this thesis employed event-related potentials (ERPs) alongside behavioural measures to explore the strategic control of recollection in a recognition exclusion task. Dual-process models of recognition memory provide a framework against which this research was conducted. The thesis is organised into three main sections. First, an overview of the theoretical and methodological background to the experiments is provided. This includes a review of theoretical models and empirical observations in relation to recognition memory. Specific issues relating to ERP methodology are then discussed, followed by a selective review of ERP studies investigating recognition memory. The second section presents the experimental work, beginning with details of methods common to all four experiments. Finally, a broad discussion of some basic experimental

findings in relation to existing theories and research is provided before the principal findings relating to the control of recollection are identified and explored.

CHAPTER 1

Recognition memory: empirical and theoretical perspectives

Recognition memory has been most commonly investigated using a study-test paradigm. This involves the presentation of a series of items at study, followed by the re-presentation of these items at test along with unstudied items. Measures of recognition memory are obtained by requesting differential responses to the two item types. Traditionally, the ability to recognise an experimentally repeated item has been explained in terms of a single matching process, based on the strength of memory traces. However, more complex dual-process models, suggesting that recognition is supported by the contribution of two qualitatively different processes, have become increasingly influential. This review is mainly concerned with the debate between single-process and dual-process models and provides the basic theoretical framework against which later experimental work is conducted and interpreted. A taxonomy of memory is first of all outlined, followed by an overview of dual-process and single-process models of recognition memory. Finally, behavioural, neuropsychological and fMRI evidence relating to these models will be discussed.

Dissociations in memory

It is now widely accepted that, far from being a unitary system, memory consists of a number of distinct and functionally dissociable component processes. This view is supported, for example, by neuropsychological data indicating that memory may be left intact for some types of information while impaired for others (e.g., Milner, 1965; 1970). One of the earliest accepted memory dissociations was

between short- and long-term memory (Atkinson & Shiffrin, 1968). Short-term memory, an attention dependent and limited-capacity system, was thought to allow information to be passed, through rehearsal, on to long-term memory, a system of limitless capacity and long duration. Long-term memory was further fractionated into explicit and implicit forms (Tulving, 1984), the former requiring the conscious recollection of information and the latter influencing specific behaviours with no requirement for conscious access into the contents of this memory store. Implicit memory performance is measured by 'indirect' tasks, for which memory retrieval is incidental to task requirements and is measured, for example, through changes in reaction time or perceptual identification while explicit memory performance is measured by 'direct' tasks such as recall or recognition. The dissociation between these two forms of memory is further supported by numerous findings that implicit memory is preserved in amnesic patients who show normal performance on 'indirect' tasks while showing impaired explicit memory performance as measured by 'direct' tasks.

The distinction between implicit and explicit forms of memory has been accounted for in a number of ways. Process-based theorists associate implicit and explicit memory with different types of processing. For example, Jacoby (1991) considers control processes to be associated with explicit memory while assuming automatic processes are associated with implicit memory. According to some transfer-appropriate processing theorists, however, explicit memory is linked to conceptually-driven processes and implicit memory is associated with perceptually-driven processes (Roediger & McDermott, 1993). Content-based explanations associate different types of information with explicit and implicit

memories. These have included context-dependent vs. context-free (Mayes, Gooding & Van Eijk, 1997; Winocur & Kinsbourne, 1978); declarative vs. procedural (Cohen & Eichenbaum, 1993; Squire, 1992), episodic vs. semantic (Kinsbourne & Wood, 1975) and associative vs. non-associative (Mayes *et al.*, 1997) for explicit vs. implicit memories, respectively. Finally, experience-based theories distinguish implicit from explicit memories by the kinds of conscious awareness that accompany each type of memory. In particular, Tulving distinguishes between three types of conscious awareness: autonoetic, noetic and anoetic (Wheeler, Stuss & Tulving, 1997). Autonoetic consciousness is related to mental time-travel and is associated with explicit memory, although specifically with episodic memory which is characterised by the retrieval of personally experienced events (see below). Noetic consciousness is also associated with explicit memory, although specifically with semantic memory. This type of explicit memory does not require any form of mental time travel, such as reliving the past, and is related to memory for facts. Anoetic consciousness is associated with implicit memory as it does not involve the mental representation of different forms of knowledge.

Nevertheless, the reactivation of a representation *per se* does not give any information about whether or not it has been previously encountered (Mayes & Roberts, 2001). According to a theory proposed by Milner (1989), explicit memory necessarily involves a trace in which a representation of the information that constitutes explicit knowledge is associated with a feeling of familiarity (cf. Jacoby, Kelley & Dywan, 1989). Furthermore, when such knowledge involves the retrieval of episodic memories, an event's familiarity will be accompanied by its

'recollection', i.e., the retrieval of the context in which this event occurred. As will be reviewed below, familiarity and recollection have been proposed to represent dissociable forms of memory that may support recognition judgements (e.g., Mandler, 1980; Jacoby & Kelley, 1992). The following sections will concentrate on the use of 'yes-no' recognition tests to measure explicit memory retrieval. This is a study-test paradigm in which participants are asked to match a retrieval cue at test to a memory trace from study by responding 'yes' or 'no' to successively presented 'old' (studied) and 'new' (unstudied) items respectively. First, relevant theoretical frameworks regarding recognition memory will be outlined.

Models of recognition memory

Recognition memory has been explained in terms of either a single, familiarity-based process which enables a test item to be matched with the contents of memory, or by the contribution of two qualitatively different processes, familiarity and recollection, that allow different bases for responding during recognition tests. The distinction between familiarity and recollection has often been illustrated by the experience of recognising a person as being 'familiar' while failing to 'recollect' any details regarding previous encounters with that person (Yonelinas, 2002). Given this view, recognition judgements could be based either on an acontextual assessment of a test item's global familiarity or on the 'episodic' retrieval of contextual information diagnostic of its source. Recollection is considered to be a relatively slow and intentional process – this episodic retrieval is accompanied by the phenomenological experience of having brought back to mind a specific event from the past. By definition, the process of recollection is assumed to be selectively engaged when contextual attributes from the study episode are

accurately retrieved and measured using what are known as 'source memory tasks'. In addition to an old/new recognition judgement, source tasks require a judgement as to the context in which the test item was originally encoded. However, even in the absence of an explicit requirement to identify an item's source, Jacoby and Whitehouse (1989) suggest that recognition tests are usually performed on the basis of recollection as the retrieval of episodic information provides a reliable basis for making a recognition judgement.

Processes of recollection are thought to be enhanced when participants engage in the deep semantic analysis of study items. If, however, participants engage only in a superficial analysis of their perceptual attributes, recollection is likely to be weak in which case familiarity is assumed to provide a more significant contribution to recognition memory (Johnston, Hawley & Elliott, 1991). Familiarity is considered to be a fast-acting and automatic process which is enhanced by the similarity of perceptual features across studied items and cues presented at test. Jacoby and Whitehouse (1989) have postulated a 'fluency heuristic' to describe the process of familiarity - increased fluency in the processing of a test item is more likely to lead to the identification of this item as having been previously seen and, therefore, judged as 'old'. Importantly, Jacoby and Whitehouse (1989) have argued that the fluency heuristic crucially involves an attributional process in that it is both the awareness of a test item having been fluently processed, as well as the attribution of this fluency to the item having been previously studied, that leads to its recognition. The facilitation of perceptual similarity between studied and test items in recognition memory has led to the notion that familiarity may be closely linked to certain implicit memory processes,

such as perceptual learning or priming (e.g., Mandler, 1980; Parkin *et al.*, 2001). However, there has been little evidence that intact priming in amnesic patients may contribute to their performance on recognition tests (e.g., Knowlton & Squire, 1995). Alternatively, it has been suggested that familiarity and recollection rely on the same explicit (or 'declarative') memory system which is thought to be dependant upon medial temporal and diencephalic brain structures as evidenced by damage to these structures in amnesic patients (e.g., Clark, Broadbent, Zola & Squire, 2002; Reed & Squire, 1999; Stark & Squire, 2001). According to this view, all tests of explicit memory, including recollection and familiarity-based recognition, necessitates the forming of associations which are held to be dependant upon the hippocampus and adjacent cortex.

Evidence that the medial temporal lobe may support processes of both recollection and familiarity has been demonstrated by a number of neuropsychological studies (e.g., Mayes, Holdstock, Isaac, Hunkin & Roberts, 2002; Stark, Bayley & Squire, 2002). For example, Stark *et al.* (2002) tested controls and amnesic patients (having bilateral lesions primarily limited to the hippocampal region) on associative tests requiring the identification of specific item pairings presented at study (necessitating recollection) and single-item recognition tests (requiring only familiarity-based recognition). In the first experiment, amnesic patients were impaired to a similar extent on single item and associative tasks in comparison to controls. Furthermore, when the number of study presentations increased from one to eight in experiment 2, the performance of amnesic patients for both single item and associative tasks was identical to controls. The authors concluded that the associative task evidenced no differential

impairment in amnesic patients, consistent with the notion that the hippocampus supports both recollection and familiarity-based recognition. However, Yonelinas *et al.* (2002) provided conflicting neuropsychological evidence in a study investigating recollection and familiarity-based memory in patients with damage to different temporal lobe regions. Hypoxic-ischemic patients with isolated damage to the hippocampus were found to have a specific impairment for recollection while showing intact familiarity-based memory responses. In contrast, patients with more extensive temporal lobe damage showed impairment for both recollection and familiarity. Therefore, this study provides evidence that different temporal lobe regions support distinct mnemonic functions of familiarity and recollection.

A number of behavioural studies have provided evidence for dissociations which also seem to support a distinction between recollection and familiarity-based recognition. For example, given speeded recognition tests, participants are able to make discriminations based on familiarity more quickly than discriminations requiring the retrieval of source information such as precisely where or when the item was encountered from the study episode (e.g., Hintzman & Caulton, 1997; Gronlund, Edwards & Ohrt, 1997; Hintzman, Caulton & Levitin, 1998). Such findings concur with theoretical accounts of familiarity and recollection. The idea that these different forms of memory reflect distinct cognitive processes has been formally expressed through dual-process models of recognition memory (e.g., Atkinson & Juola, 1974; Jacoby & Kelly, 1992; Mandler, 1980; Tulving, 1985) and will be reviewed below.

Dual-process models

The basic tenet of dual-process models is that recognition comprises two qualitatively distinct memory processes, familiarity and recognition. To summarise, familiarity is conceptualised as an automatic and fast-acting process, the phenomenal experience of the retrieved memory being a lack of awareness for any contextual details from the study episode. In contrast, recollection is considered to be a relatively slow and largely intentional process, and the retrieved memory is accompanied by conscious access to contextual information from study. It has been suggested that the relationship between the processes of familiarity and recollection could, theoretically, include one of three alternatives: independence, exclusivity and redundancy (Jones, 1987). Independence refers to the possibility that familiarity and recollection may occur either together or separately while exclusivity suggests that these two processes may never co-occur. The redundancy view proposes that, while familiarity may occur without recollection, recollection cannot occur without familiarity. A number of methods have been developed to evaluate the theoretical claims regarding recollection and familiarity, each relying on a number of critical assumptions. Two of the most important methods in relation to ERP studies (see Chapter 3: 'ERP studies of recognition memory') are the Process Dissociation Procedure (Jacoby, 1991) and the Remember / Know Paradigm (Tulving, 1985; Gardiner, 1988).

Remember / Know Paradigm

The remember / know paradigm was first introduced by Tulving (1985) who identified 'remembering' with episodic (or 'autonoetic') memory - the recollection of past events - and 'knowing' with semantic (or 'neotic') memory -

the retrieval of information in the absence of a specific recollective experience. This paradigm was later developed for use in estimating the contributions of familiarity and recollection in recognition memory performance (Gardiner, 1988; Gardiner & Java, 1990; 1993). This phenomenological approach relies on subjective reports - participants are asked to respond 'remember' if they can recollect specific information from the study phase and 'know' if they recognise the test item in the absence of recollection. Therefore, it is assumed that the remember / know distinction is equivalent to the recollection / familiarity distinction and that the subjective reports could be used to supplement objective accounts of recognition memory (Gardiner & Java, 1993). In fact, after studying transcripts of participants' rationales for making 'know' and 'remember' responses, Gardiner and Ramponi (1998) found that, in relation to 'know' responses, there was no evidence of any contextual details having been retrieved. One advantage of deriving measures of familiarity and recollection based on subjective reports is that, using the remember / know procedure, recollected items may include any contextual information from the study episode whereas, using objective measures, they may only include specified contextual (i.e., 'source') information (Yonelinas, 2002). Indeed, based on the transcripts mentioned above, the basis for having made a 'remember' response fell into one of five categories: (1) intra-list associations; (2) extra-list associations; (3) item-specific imagery; (4) the item's physical features; and (5) self-reference (Gardiner & Ramponi, 1998).

A number of different encoding variables have been found to differentially affect 'remember' and 'know' responses (for reviews, see Rajaram & Roediger, 1997; Gardiner & Richardson-Klavehn, 2000). For example, four sets of

experimental manipulations at study that have differential effects on 'remember' and 'know' responses at test have been identified by Gardiner and Richardson-Klavehn (2000). A set of variables, known to differentially engage conceptual and elaborative processing and which influence 'remember' responses while having little effect on 'know' responses, include levels of processing (Gardiner, 1988), divided attention (Gardiner & Parkin, 1990), retention interval (Gardiner & Java, 1991) and generating vs. reading (Gardiner, 1988). Variables related to perceptual processing that have been shown to selectively influence know responses include manipulations of surface features, e.g., modality correspondence, across study and test (Gregg & Gardiner, 1994) and maintenance rehearsal (Gardiner, Gawlik & Richardson-Klavehn, 1994). Other variables have been shown to affect remember and know responses in opposite directions, e.g., repetition of previously novel melodies (Gardiner, Kaminska & Dixon, 1996), as well as to have comparable effects on both responses, e.g., increased response deadlines (Gardiner, Ramponi & Richardson-Klavehn, 1999).

The above findings support the notion that remember and know responses reflect different states of awareness associated with recognition. However, a number of difficulties have been identified with this paradigm. These include the assumption of an exclusivity relationship between the processes of familiarity and recollection due to remember and know responses being, necessarily, mutually exclusive. In fact, this assumption is inconsistent with other dual-process models and, consequently, the method has been found to underestimate the contribution of familiarity (Yonelinas & Jacoby, 1995). This is because participants are instructed to respond 'know' only when a test item is familiar in the absence of recollection.

Therefore, familiarity in the presence of recollection is ignored. However, a remember / know measurement which assumes a relationship of independence was developed to compensate for this underestimation (Yonelinas & Jacoby, 1995). Rather than deriving an estimate of familiarity simply from the proportion of know responses ['know' = F(1 - R)], this method instead calculates an estimate of familiarity to be the probability that an item receives a know response given that it was not recollected [F = 'know'/(1-R)]. Another criticism has been aimed at the one-stage remember/know procedure, for which participants are instructed to respond new, know or remember as this procedure led to a higher false alarm rate for know responses than for remember responses. As this indicated that participants were treating the two responses as confidence judgements, it was suggested that a two-step remember/know procedure should be used, for which participants are required to first identify whether items are old (Hicks & Marsh, 1999). Gardiner and Conway (1999) have also suggested that, in addition to know and remember responses, a guess should also be included as know responses were often contaminated by guessing.

Process Dissociation Procedure (PDP)

The Process Dissociation Procedure (PDP) quantifies the contributions of familiarity and recollection to performance in recognition tasks using objective methods. This procedure was developed by Jacoby (1991) which employs two opposing tasks, 'inclusion' and 'exclusion' tasks, to both separate and estimate the contributions of familiarity and recollection to recognition memory performance. It was argued that items in a recognition memory test may be recognised either on the basis of recollection, which can be intentionally controlled, or on the basis of

automatic familiarity processing, which cannot be brought under control. Two classes of item are presented at study. For the *inclusion* task, participants are required to respond 'old' to all studied items. However, the *exclusion* task requires participants to respond 'old' to only one specified class of items from study and to respond 'new' to both unstudied items as well as to all other non-specified studied items – i.e., these must be rejected or 'excluded'. It is assumed that recognised items from the inclusion task reflect the contributions of both familiarity and recollection. However, differential responding to the two classes of studied items in the exclusion task may only be achieved through intentional and controlled recollection of their study source – automatic processes of familiarity would not allow for selective responding. Based on these assumptions, a series of equations are subsequently calculated (where R = recollection and F = familiarity). For the inclusion task, the probability of recognising an item from the (unspecified) class of studied items is equal to the probability (P) that the item is recollected plus the probability that the item is familiar in the absence of recollection:

$$[P(\text{Inclusion}) = R + F\,(1 - R)].$$

Under exclusion conditions, however, the probability that an item is recognised from the unspecified class of items is equal to the probability that the item is familiar in the absence of recollection:

$$[P(\text{Exclusion}) = F\,(1 - R)].$$

The parameters of familiarity and recollection are estimated by contrasting inclusion and exclusion performance:

$$[\text{Recollection} = P(\text{Inclusion}) - P(\text{Exclusion})];\ [\text{Familiarity} = P(\text{Exclusion}) / (1 - R)].$$

The PDP assumes a relationship of independence between familiarity and recollection. However, it has become apparent that the independence assumption may only hold within certain boundary conditions (Yonelinas, 2002). A further problem with this procedure is the assumption that criteria used for familiarity-based judgements in the inclusion and exclusion tasks are equivalent. Similarly, it is assumed that the use of recollection is equally likely in both tasks. As different test instructions accompany the two tasks, these assumptions may not necessarily hold and parameter estimates may well be influenced. To address this problem, modified procedures have now been developed in which test instructions are equivalent for the two tasks (e.g., Yonelinas & Jacoby, 1994). Furthermore, inclusion and exclusion test trials can be embedded within the same test to ensure the use of recollection in both conditions (e.g., Jacoby, Toth & Yonelinas, 1993). Another criticism of the PDP is that it confounds intentional retrieval with states of awareness and, therefore, is unable to account for the phenomenon of involuntary conscious memory (Schacter, 1987; Richardson-Klavehn, Gardiner & Java, 1994). In a similar vein, the PDP does not take non-criterial recollection into account given that this procedure requires the retrieval of specified contextual information. Yonelinas and Jacoby (1996) argued, however, that recollection is defined by the task demands, highlighting a key difference between the PDP and phenomenological accounts. Whereas proponents of the PDP defines recollection as the retrieval of episodic information in service of the conscious control of behaviour (e.g., Jacoby & Kelley, 1992), phenomenological accounts emphasise recollection in terms of conscious experience, regardless of whether this was a consequence of controlled retrieval. In any case, it was found that the effects of

non-criterial recollection were independent from those of criterial recollection, and that non-criterial recollection demonstrates characteristics that are functionally similar to those of familiarity (Yonelinas & Jacoby, 1996).

Yonelinas' model

A dual-process model proposed by Yonelinas and colleagues (Yonelinas, Dobbins, Szymanski, Dhaliwal & King, 1996) assumes that recollection reflects a discrete, threshold process whereby qualitative information from the study episode may be retrieved. In contrast, familiarity assessment is thought to reflect a continuously distributed signal-detection process whereby familiarity distributions for both new and old items overlap to produce positive recognition responses for new items ('false alarms') as well as for old items ('hits'). Therefore, in this model, a response criterion is set along the continuum where the old and new distributions overlap such that only items above this criterion level will be accepted as being recognised (see figure 1.1 below). A competing class of models, single-process models of recognition memory, suggest that performance on recognition tasks may

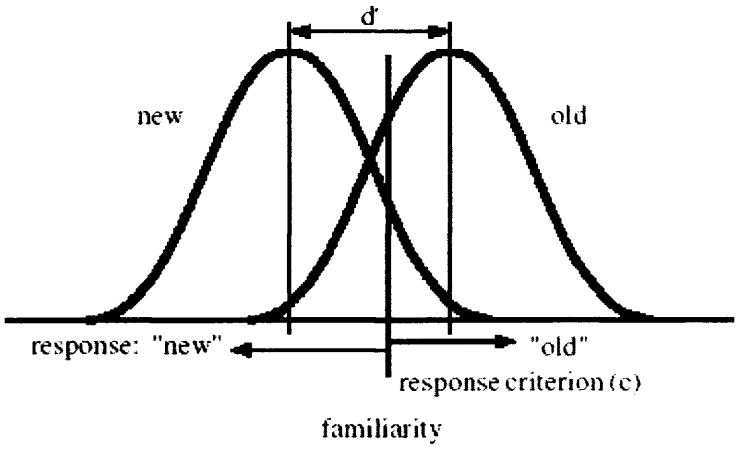

Figure 1.1: Old and new item familiarity distributions: an equal-variance signal-detection model. From Yonelinas (2001).

instead reflect only a single familiarity signal-detection process. However, the study of receiver operating characteristics (ROCs) has proved to be problematic for single-process models. A ROC function is produced by plotting the proportion of correct recognition responses (i.e., the 'hit' rate) against the proportion of incorrect recognition responses (i.e., the 'false alarm' rate) as the response criterion is varied. This is achieved by examining recognition performance across different levels of response confidence. As shown by figure 1.2, recognition responses accompanied with the highest level of confidence are represented on the far left of the ROC curve and subsequent points along the curve represent recognition responses accompanied with decreasing levels of confidence. Figure 1.2 demonstrates two types of recognition memory ROCs. The lower function is curvilinear and symmetrical against the diagonal. The curvilinear shape reflects the continuous nature of Gaussian familiarity distributions and is symmetrical because the old and

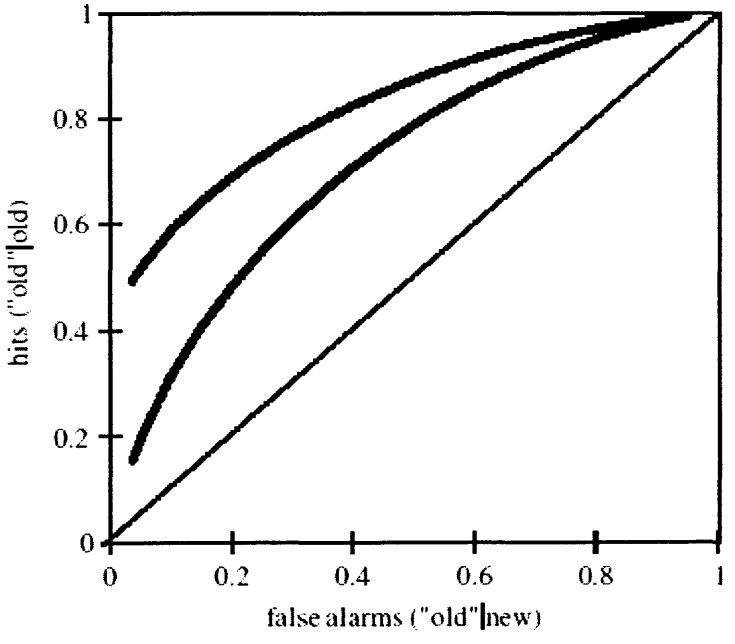

Figure 1.2: Asymmetrical (upper function) and symmetrical (lower function) receiver operating characteristics. From Yonelinas (2001).

new item distributions have equal variance. Such characteristics were typical of early recognition ROCs (e.g., Murdock & Dufty, 1972) and supported the view that recognition memory reflected only a single familiarity component that could be measured using a single parameter (e.g., d') denoting the distance between the means of the new and old familiarity distributions and was independent of response bias. However, later studies have shown that recognition memory often produces asymmetrical ROCs, as shown by the upper function in figure 1.2, and, with the left-most point higher along the y-axis, indicates greater variance associated with the old item distribution in comparison to the new item distribution.

The asymmetry of the ROC curve is not, in itself, problematic for single-process models as this could reflect a number of possibilities which would still allow for recognition memory performance to be measured using a single parameter. For example, if the degree of asymmetry was constant, this might suggest that old item distributions always show greater variance than new item distributions. Alternatively, the degree of asymmetry might change in direct relation to recognition accuracy - for example, increasing as recognition accuracy increases (Yonelinas, 2002). However, the degree of asymmetry in recognition ROC curves is not constant and is functionally independent of recognition accuracy (e.g., Glanzer, Kim, Hilford & Adams, 1999). This suggests that two distinct components are necessary to account for recognition ROC curves – one to explain increases in sensitivity (e.g., d') and another to explain the differential changes in variance found in old and new item distributions. It is this aspect of the ROC function data that has provided the greatest challenge for single-process models of recognition memory.

Single-process models

Single-process models propose that recognition memory reflects a single signal detection process based on global familiarity and that recollection may play only a minimal role in recognition judgements. In using a signal-detection process, these models propose two familiarity distributions, one for studied (old) items and one for new items. Although old items will, generally, be more familiar than new items, old and new item familiarity distributions will, nevertheless, overlap, producing positive recognition responses both for new items ('false alarms') as well as for old items ('hits'). Therefore, a response criterion is set whereby only items above this criterion level will be accepted as being recognised. In this way, these models need only employ a single parameter of sensitivity (d') with which to characterise recognition accuracy. A subset of single-process models are known as 'global-matching models': 'Search of associative memory model' or 'SAM' (Gillund & Shiffrin, 1984); 'MINERVA 2' (Hintzman, 1988); 'Theory of distributed associative memory' or 'TODAM' (Murdock, 1982). These models are so called, first, because it is assumed that a test item will access a great number of items in memory and, second, because it was intended that the models could explain data from a wide range of experimental manipulations and tasks (Ratcliffe & McKoon, 2000). Although these models differ in terms of specific assumptions underlying retrieval, they also share a number of common views. The three models agree that a test cue may be combined with the context in which it is presented to produce a single probe of memory which will then access multiple items in memory simultaneously (Clark & Gronlund, 1996). The total activation of this 'global level' access results in a scalar value which is generally thought to index

the level of global familiarity (Ratcliffe, Van Zandt & McKoon, 1995). Therefore, if the scalar value is higher than criterion, a positive recognition judgement will be made.

These models account for both item and associative recognition using a single retrieval process although the retrieval process is conceptualised in different ways for each model. However, as the retrieval of associative recognition requires the discrimination of intact from rearranged studied pairs at test, proponents of the dual process framework would argue that associative recognition could only be based on recollection. This is because the recovery of information about word pairing is only available if memory for the original study episode is retrieved. According to this argument, familiarity-based recognition cannot support associative recognition judgements. Furthermore, a number of findings suggest that item recognition can be dissociated from associative recognition at retrieval. For example, Gronlund and Ratcliff (1989) have shown, using a signal-to-response procedure (Reed, 1973), that the performance function for item recognition rises above chance approximately 150 msec earlier than the performance function for associative recognition, suggesting that these two types of information make separate contributions to recognition (Clark & Gronlund, 1996). In contrast, global matching models would predict the simultaneous availability of item and associative information at retrieval.

Unlike the other global matching models, SAM does distinguish between item and associative information at the level of representation but still assumes that both types of information are retrieved simultaneously. Findings of a delay in performance function for associative recognition has been suggested to reflect the

operation of a slower recall process, and other findings support this notion - for example, associative recognition shows a high-frequency word advantage, as has been found for recall, but not for item recognition (e.g., Clark, 1992; Clark & Burchett, 1994). Modifications to SAM have involved the inclusion of a cued-recall strategy in that individual words may be used as cues to recall correct study pairings. More recently, a two-criteria signal-detection model has been proposed to examine the dissociations found in using the remember / know paradigm (Donaldson, 1996).

Two-criteria signal-detection models

In accord with other single-process models, two-criteria signal detection models also propose a single continuously distributed familiarity process (Donaldson, 1996). However, in order to accommodate the dissociations between remember and know responses the two-criteria signal detection models propose the addition of a second response criterion (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998). While items above the first response criterion are identified as old, a second response criterion divides old responses attracting a 'know' response from those attracting a 'remember' response, reflecting weak versus strong memory traces respectively. This model makes two main predictions and demonstrates how findings from studies using the remember / know procedure can be explained within a single-process model. The first prediction is that a non-parametric measure of memory sensitivity (A′) will be approximately equal across 'old' and 'remember' responses (as 'remember' responses are only conservative 'old' responses). The second prediction is that memory based on 'know' responses should be correlated with the old/new response criterion. To help illustrate the logic

behind both predictions, schematic diagrams showing the effect of conservative (top), neutral (middle) and liberal (bottom) response criteria on 'remember' and 'know' responses are presented in figure 1.3. Figure 1.3 demonstrates that the hit rate (i.e., the area to the right of the old/new criterion and under distribution B) and the false alarm rate (i.e., the area to the right of the old/new criterion and under distribution A) increase as the old/new criterion becomes more liberal. As items to the right of the remember/know response criterion are identified as 'remember' responses, these simply represent conservative 'old' responses. However, while hit rates and false-alarm rates for 'remember' responses will be lower than for overall 'old' responses, measures of sensitivity (A′ or d′) for 'remember' responses should be no different to those for 'old' responses (i.e., because sensitivity measures provide a criterion-free estimate of memory performance). Findings from Donaldson's (1996) recognition memory experiment support this prediction, showing no significant differences between measures of overall recognition performance (A′ = 0.825) and measures of remember performance (A′ = 0.837). The distributions in figure 1.3 could also describe two sets of old items in a recognition memory task – distribution A could represent the more difficult level of a variable in a recognition experiment and distribution B could represent the easier level (Donaldson, 1996). The remember hit rate (i.e., to the right of the remember/know response criterion) will always be higher under distribution B (easy condition) than under distribution A (difficult condition) in parallel with overall recognition hit rates. However, a different pattern emerges for 'know' responses depending upon the placement of the old/new response criterion. With a conservative response criterion (top panel of figure 1.3), the 'know' hit rate is

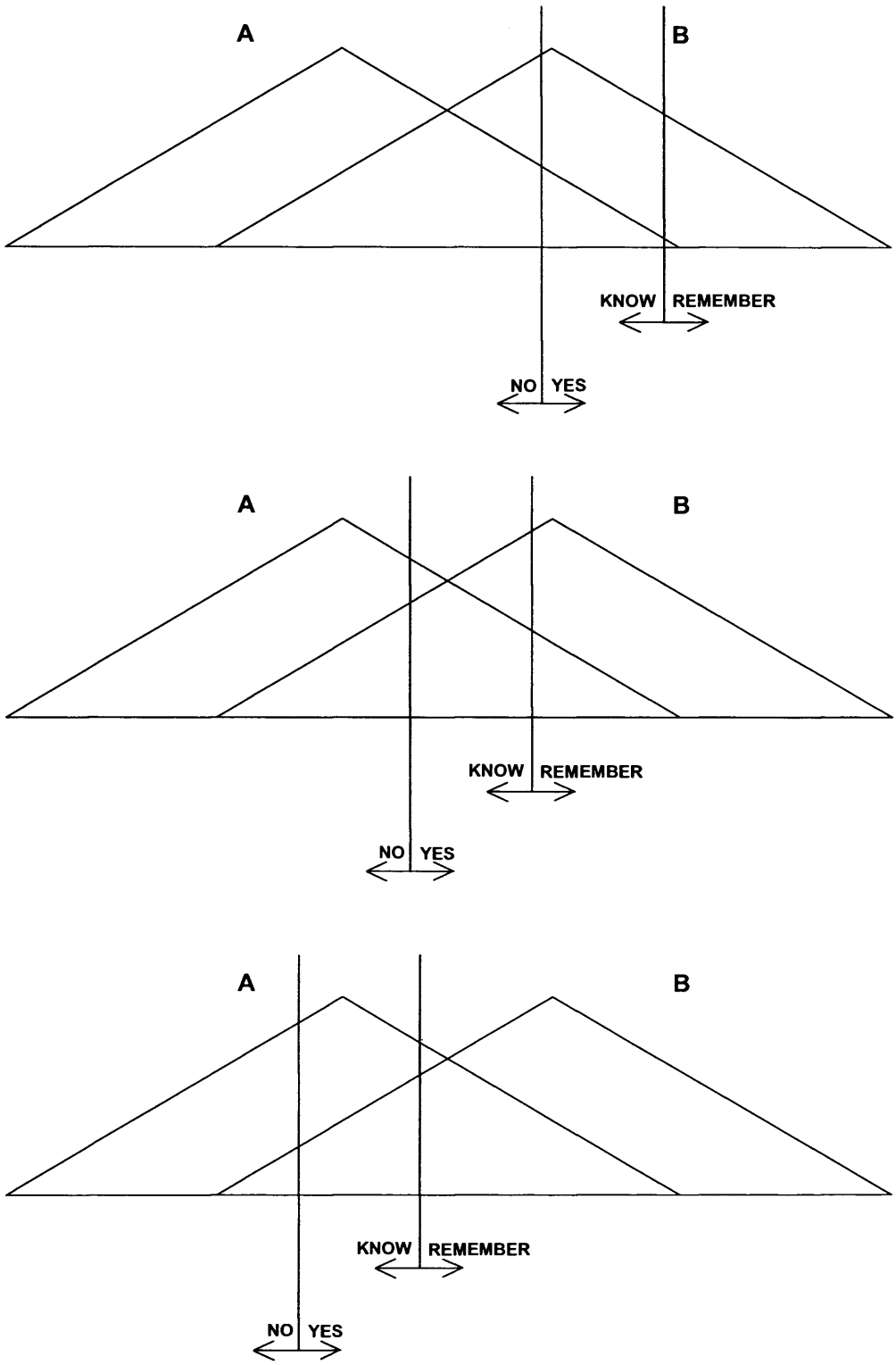

Figure 1.3: Schematic diagrams showing the effect of different response criterion – conservative (top), neutral (middle) and liberal (bottom) – on remember and know responses when considered as weaker and stronger components of recognition. Adapted from Donaldson (1996).

higher under the easy condition (distribution B) in comparison to the difficult condition (distribution A) – the same as is predicted for the 'remember' hit rate. With a neutral response criterion (middle panel of figure 1.3) the 'know' hit rate is equivalent under the two conditions. Therefore, in contrast to the 'remember' hit rate, the 'know' hit rate is unaffected by task difficulty, demonstrating a dissociation between 'remember' and 'know' hit rates as manipulated by task difficulty. Finally, with a liberal response criterion (bottom panel of figure 3), the 'know' hit rate is higher under the difficult condition (distribution A) in comparison to the easy condition (distribution B). In this way, a crossover interaction is demonstrated – while the 'know' hit rate is higher in the difficult condition compared to the easy condition, the 'remember' hit rate remains higher under the easy condition (Donaldson, 1996). Although Donaldson (1996) suggests that single-process models may not account for all dissociations held to support dual-process models, it seems that the dissociations demonstrated in the remember/know literature may be accounted for by the two-criteria signal-detection model.

It has been pointed out, however, that the two-criteria signal detection model does not explain how subjectively distinct states of awareness can be elicited simply by shifting response criteria in different directions over the same memory trace. Rather, it would seem capable only of modelling the responses (Gardiner & Richardson-Klavehn, 2000). It has also been found that estimates of the strength of the memory trace changes according to the response criteria used to estimate it. For example, a procedure introduced by Gregg and Gardiner (1994) have shown that the estimates of the strength of the memory trace are much greater when derived

from remember plus know responses than when derived only from remember responses. Such differences in the same direction have been consistently observed for many different experimental conditions (Donaldson, 1996; Gardiner & Gregg, 1997). Therefore, it would seem that 'knowing' reflects an additional source of memory rather than simply a difference in response criteria (Gardiner & Richardson-Klavehn, 2000).

So, the two-criteria signal-detection models, in some respects, would seem to provide a viable alternative to dual-process models. Nevertheless, such models fail to account for many of the behavioural dissociations that have been held to support dual-process models, including some of those demonstrated within the remember/know literature. On the face of it, dual-process models would seem to provide the most comprehensive account of recognition memory. To further explore the plausibility of dual-process models, the following sections provide an overview of behavioural, neuropsychological and functional neuroimaging findings which address the issues outlined above with regard to models of recognition memory.

Behavioural evidence

Behavioural studies can provide evidence for models of recognition memory by demonstrating whether or not an experimental manipulation can have dissociative effects on the proposed components of recognition memory – familiarity and recollection. A number of independent variables have shown differential effects on familiarity and recollection within studies employing the remember/know paradigm and the PDP. For example, in comparison to familiarity,

recollection is relatively more sensitive to depth of processing manipulations (e.g., Toth, Reingold & Jacoby, 1994) – i.e., recollection is enhanced when participants engage in the 'deep', semantic analysis of study items rather than in a more superficial or 'shallow' analysis of their perceptual attributes. Using the remember / know paradigm, Gardiner (1988) reported that a depth of processing effect was totally accounted for by 'remember' responses, while 'know' responses remained unaffected by this manipulation. In contrast, other studies, using the PDP, have also reported depth of processing influences on familiarity (Toth, 1996; Jacoby & Kelley, 1991). However, these discrepant findings were accounted for when the remember / know data, having been originally analysed under the exclusivity assumption, was reanalysed under the independence assumption. The reanalysis showed a depth of processing effect in the same direction for both 'remember' and 'know' responses (Wagner, Gabrieli & Verfaellie, 1997). It has more recently been reported, however, that one component of familiarity seems to be sensitive to depth of processing manipulations while another component is not (Yonelinas, Kroll, Dobbins, Lazzara & Knight, 1998).

Dividing attention during study has been found to selectively affect 'remember' responses (e.g., Gardiner & Parkin, 1990) as well as recollection in studies employing the PDP (e.g., Jacoby, 1991). Further evidence that attentional capacity selectively influences recollection was provided by another study employing the PDP, using a list length manipulation at study (Yonelinas & Jacoby, 1994). It was argued that, in augmenting study list length, demands on attentional capacity increase – this manipulation selectively reduced estimates of recollection but not familiarity (Yonelinas & Jacoby, 1994). However, it has been argued that

one of the single-process models (SAM) could also account for these data (Ratcliffe *et al.*, 1995). This can be achieved by increasing familiarity values for items from longer lists as well as increasing variability in their familiarity values. For example, for new items presented at test, familiarity will be twice as large for lists that are twice as long. Therefore, the familiarity criterion separating old and new responses needs to be moved as the list length changes so that it may remain between the old and new item distributions. Further support for dual process models, however, come from studies of speeded recognition. These have indicated that estimates of recollection are reduced when participants are required to respond at a fast, rather than a slow, deadline, while estimates of familiarity are not influenced by this manipulation (Yonelinas & Jacoby, 1994). This suggests, as would be predicted, that familiarity is available earlier than recollection – in fact, it has been reported that accurate old/new judgements can be made approximately 100 msec prior to accurate source judgements (Hintzman, Caulton & Levitin, 1998). The few variables held to selectively influence familiarity are those that increase the perceptual fluency with which items are processed. For example, briefly flashing an item immediately prior to presenting the same item at test increases the probability that the word will be recognised as old. This type of manipulation has been found to increase 'know' responses while leaving 'remember' responses unaffected (e.g., Rajaram, 1993). Also, matching the modality between study and test produces a higher proportion of 'know' responses than when modality shifts between study and test, while remember responses remain unaffected by this manipulation (Gregg & Gardiner, 1994).

Neuropsychological evidence

It is well established that damage to the medial temporal lobes causes severe impairments in explicit recognition performance (e.g., Moscovitch & McAndrews, 2002; Yonelinas *et al.*, 1998). Damage to the hippocampus and surrounding temporal lobes in amnesic patients has been shown to disrupt both recollection and familiarity, but generally has a larger disruptive effect on recollection. For example, amnesic patients generally exhibit disproportionate deficits on associative- compared to item-recognition tests, indicating that recollection is disproportionately disrupted by medial temporal lobe damage. Specifically, in comparison to tests of item recognition, amnesic patients perform more poorly in tests that require them to remember when an item was presented (e.g., Aggleton *et al.*, 2000; Kopelman, 1989; Nunn *et al.*, 1999). Consistent with such examples, ROC studies in amnesic patients have indicated that only one process (i.e., familiarity) is needed to account for their recognition performance (Yonelinas *et al.*, 1998), as would be expected if they exhibited a severe deficit in recollection. Furthermore, results from the remember/know (Blaxton & Theodore, 1997; Knowlton & Squire, 1995; Schacter, Verfaellie & Anes, 1997; Schacter, Verfaellie & Pradere, 1996), process-dissociation (Verfaellie & Treadwell, 1993) and ROC (Yonelinas *et al.*, 1997) estimation methods indicate that, in studies which include patients with extensive temporal lobe damage, recollection is severely disrupted, whereas familiarity is disrupted to a lesser extent. These findings indicate that recognition tests that can be based on familiarity are functionally distinct and rely on partially separate neural substrates than those that require participants to recollect information about the study event. Such

dissociations would be expected if recognition performance may rely on two distinct memory processes. In contrast, if all recognition memory judgements are based on the assessment of a single form of memory, then these types of dissociations should not have been observed.

However, it has been suggested that it is actually focal damage to the hippocampus that appears to disrupt recollection rather than familiarity. Given anatomical differences between the hippocampal and parahippocampal regions of the medial temporal lobes (Lavanex & Amaral, 2000), a number of researchers have proposed that these sub-regions may support distinct memory processes (e.g., Aggleton & Brown, 1999; Eichenbaum & Cohen, 2001; Shastri, 2002). Based on an extensive review of neuropsychological and neurophysiological studies in rats, monkeys and humans, Aggleton and Brown (1999), for example, have proposed that, while the hippocampus supports recollection, regions within the parahippocampal gyrus support familiarity-based recognition. Results from a number of neuropsychological studies support the view that the hippocampus is disproportionately critical for recollection whereas parahippocampal regions can support familiarity-based recognition (e.g., Aggleton & Shaw, 1996; Baddeley, Vargha-Khadem & Mishkin, 2001; Duzel, Vargha-Khadem, Heinze & Mishkin, 2001; Mayes *et al.*, 2002, Yonelinas *et al.*, 2002). There is, however, evidence that some forms of associative recognition may be more disrupted by hippocampal damage than others. For example, Mayes and colleagues (Mayes, van Eijk, Gooding, Isaac & Holdstock, 1999; Mayes *et al.*, 2001) reported that a patient with hippocampal damage exhibited disproportionate deficits on temporal order, object-place, and voice-face associative recognition tests compared to word-word

associative recognition. Vargha-Khadem and colleagues (1997) reported similar findings for three patients with hippocampal damage who exhibited deficits in recognition for face-voice and object-location associative recognition, but who performed normally on word-word and face-face associative recognition. These results suggest that the hippocampus is necessary for the formation of associations between items or aspects of an event that involve different types of information or that are processed by different cortical regions (e.g., face processing versus word processing regions). However, the hippocampus may not be necessary when the different aspects of an event involve the same type of information (Yonelinas, 2002).

Results from other studies suggest that both the hippocampus and the parahippocampal regions may support familiarity and recollection to an equivalent degree (Manns, Hopkins, Reed, Kitchener & Squire, 2003; Stark & Squire, 2001; 2003). Squire and Knowlton (2000) have made the interesting proposal that, while familiarity and recollection may be functionally distinct, they are both forms of explicit memory that depend upon integrated processing within the medial temporal lobes. They suggest that dissociations between recollection and familiarity may reflect the disproportional dependence of recollection on strategic processing mediated by the prefrontal cortex (Davidson & Glisky, 2002; Knowlton & Squire, 1995; Manns *et al.*, 2003). Consistent with this view, several neuropsychological studies suggest that, while recognition memory is relatively preserved in patients with prefrontal cortex lesions, their performance is impaired on free recall and source memory tests that are both thought to rely on recollection (see Ranganath & Knight, 2003, for a review). The dorsolateral region of the

frontal lobes appears to be particularly important for recollection – for example, associative recognition memory deficits are observed in patients with dorsolateral prefrontal lobe lesions but not in frontal lobe patients for whom dorsolateral regions are spared (Kopelman, Stanhope & Kingskey, 1997). In contrast, a patient with focal damage to the right ventral prefrontal region was found to perform normally on recognition, associative recognition and recall tests, but correct recognition responses were associated with fewer remember and more know responses than seen in controls (Levine *et al.*, 1998; Levine, Freedman, Dawson, Black & Stuss, 1999). This suggests that ventral prefrontal damage may disrupt the subjective experience of recollection or the ability to report on recollection, even when the ability to recollect associative information about previous events is preserved (Yonelinas, 2002).

Functional neuroimaging evidence

Functional neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), have provided data to complement neuropsychological findings. In particular, fMRI techniques offer a number of advantages over neuropsychological research in terms of the precise spatial localisation of functional differentiation obtained within specific brain regions. This haemodynamic method detects changes in regional blood oxygenation, providing indirect measures of brain activity due to the coupling of these local changes and neural activity (Rugg & Wilding, 2000). A number of (event-related) fMRI studies have investigated differential neural activity as a function of conscious experience accompanying retrieval in recognition tasks (see the following chapter for further details on event-related methodology). For example, Eldridge, Knowlton,

Furmanski, Bookheimer and Engel (2000) employed the remember / know procedure using the 2-step response method. In contrast to recognised items judged as known, those judged as remembered elicited enhanced activity in lateral parietal cortex, left hippocampus and left dorsolateral prefrontal cortex. Similarly, Henson, Rugg, Shallice, Josephs and Dolan (1999), using the single response remember / know procedure, found enhanced activity for items associated with remember judgements compared to those associated with know judgements in lateral parietal cortex and left dorsal anterior prefrontal cortex. Unlike Eldridge *et al.* (2000), however, Henson *et al.* (1999) did not find greater hippocampal activity for items judged as remembered. Given the number of patient studies indicating the involvement of the hippocampus in recollection, it is surprising that such negative results have often been reported in event-related fMRI studies of recognition memory (although see also Wheeler & Buckner, 2004, for positive findings). It has been suggested that, as hippocampal activity has been demonstrated during the encoding of new items that have been subsequently remembered (Otten & Rugg, 2001), contrasts between studied and unstudied items may fail to reveal retrieval-related effects because these are negated by the encoding-related activity elicited by unstudied items (Rugg, Otten & Henson, 2002).

The findings reported by Eldridge *et al.* (2000) and Henson *et al.* (1999) suggest that the engagement of lateral parietal and left anterior prefrontal regions may specifically reflect processes of recollection. This is consistent with reports from a study that employed the exclusion task which showed greater activations in left anterior prefrontal and lateral parietal cortex for excluded studied items (known as 'non-targets') in comparison to new items (Rugg, Otten & Henson, 2002). As

reviewed earlier in the chapter, the correct exclusion of non-targets are thought to require the recollection of their study context so that they can be discriminated from equally familiar 'targets' associated with an alternative study context (Jacoby, 1991). Left prefrontal activations in relation to episodic retrieval have previously been interpreted as markers of additional 'reflective' processes that operate on information requiring detailed evaluations (Nolde, Johnson, D'Esposito, 1998). However, in contrast to the reflective hypothesis, alternative accounts suggest that left ventrolateral prefrontal cortex activation reflects the successful retrieval of episodic details or operations contingent upon retrieval success (Henson *et al.*, 1999; Konishi, Wheeler, Donaldson & Buckner, 2000). Therefore, there is some uncertainty regarding the nature of left prefrontal cortex contributions to episodic memory. In a very recently reported fMRI study, Yonelinas and colleagues (Yonelinas, Otten, Shaw & Rugg, 2005) demonstrated that both anterior and posterior regions of the left lateral prefrontal cortex was, in fact, related to familiarity with high levels of recognition confidence. These authors suggest that previous findings of greater left lateral prefrontal cortex for remembered items in comparison to known items (Henson *et al.*, 1999; Eldridge *et al.*, 2000) may have arisen because recollected items also tend to be associated with high recognition confidence.

Another prefrontal region that has been associated with recognition confidence is the right dorsolateral region. In Henson *et al.'s* (1999) study, this region was elicited by recognised items judged as known in comparison to those judged as remembered. It was suggested that a know judgement, being based on weaker evidence than a remember judgement, may require greater monitoring of

the products of a retrieval attempt and that this right dorsolateral activation may reflect such monitoring (Henson *et al.*, 1999). In a follow-up study (Henson, Rugg, Shallice & Dolan, 2000), recognition was accompanied by confidence ratings rather than remember / know judgements – these authors predicted greater monitoring for both 'old' and 'new' items assigned a low confidence rating. Consistent with Henson *et al.*'s (1999) proposal, correctly classified old and new items showed enhanced activation in the right dorsolateral region when assigned a low, in contrast to a high, confidence rating. These findings suggest a role for specific prefrontal regions in controlled processes that generalise to decisions involving minimal recollective content (cf. Wheeler & Buckner, 2004). Both cognitive theory and neuropsychological evidence suggest there may be at least two controlled operations that are more involved in source memory tasks than in item memory tasks (e.g., Burgess & Shallice, 1996; Schacter, Schacter, Norman & Koutstaal, 1998; Tulving, 1983). First, there is 'retrieval cue specification' which relates to the semantic relationship between the retrieval cue and the known characteristics of the potential sources. In other words, it is thought that efficient retrieval from episodic memory may depend on the ability to use semantic knowledge in order to systematically consider the most relevant characteristics of a current memory cue in relation to potential previous episodes (e.g., Schacter *et al.*, 1998). The second proposed operation is the process of evaluating the products of memory retrieval with respect to their relevance to the retrieval task. Unlike item recognition tests when items can be simply endorsed on the basis of familiarity, for tasks requiring source decisions, information may be recollected that varies

considerably with regard to task relevancy. In this case, retrieved information must be evaluated to determine whether it is relevant to the current task.

In considering the above proposals, Dobbins, Foley, Schacter and Wagner (2002) examined activity across semantic encoding, source recognition and item recognition tasks. These authors suggested that, if controlled semantic analysis / selection of semantic features are required to specify effective retrieval cues for source recognition and to analyse task-relevant semantic features during encoding, anterior left inferior prefrontal cortex, an area related to semantic retrieval and selection (e.g., Buckner, Raichle & Petersen, 1995; Wagner, Koutstaal, Maril, Schacter & Buckner, 2000; Wagner, Pare-Blagoev, Clark & Poldrack, 2001), should be activated in both tasks. In contrast, item recognition should not engage this brain region as controlled semantic analysis would not be required for this task (Fletcher & Henson, 2001). Furthermore, Dobbins *et al.* (2002) suggested that the monitoring requirements of source memory should recruit unique control processes given that neither item recognition nor semantic encoding should require the monitoring or evaluation of the outcome of episodic retrieval. In line with these proposals, Dobbins *et al.* (2002) reported that source memory tasks, relative to item recognition, differentially requires distinct cue specification and monitoring operations that are supported by anatomically separable left prefrontal regions. More specifically, their pattern of findings suggested that anterior left inferior prefrontal cortex is involved in the controlled retrieval of semantic information that is necessary during semantic encoding and is a critical component of cue specification during a source retrieval attempt. However, frontopolar and posterior dorsolateral prefrontal cortex regions were exclusively engaged during the source

task, suggesting a role in control processes that guide the monitoring or evaluation of the contents of episodic retrieval. Furthermore, consistent with the idea that the engagement of such processes in the controlled aspects of source memory is necessary regardless of task outcome, the degree of prefrontal activity was found to be insensitive to retrieval success (Dobbins *et al.*, 2002).

In sum, the above findings indicate that episodic memory is supported by a number of prefrontal brain regions associated with cognitive control processes that guide and monitor episodic retrieval attempts. Many of these prefrontal regions would seem to be associated with both recollection and familiarity-based judgements, although Yonelinas and colleagues (2005) have recently identified the anterior medial prefrontal cortex as being specifically associated with recollection. It would also seem that the lateral parietal cortex and hippocampus make selective contributions to recollection-based recognition memory (cf. Yonelinas *et al.*, 2005). Furthermore, there is accumulating evidence that certain regions of the brain that process incoming sensory information may be involved in the subsequent retrieval of that information from memory (e.g., Nyberg, Habib, McIntosh & Tulving, 2000; Nyberg *et al.*, 2001; Wheeler & Buckner, 2003; Wheeler, Peterson & Buckner, 2000). Alongside evidence from behavioural and neuropsychological studies, fMRI findings provide strong support for dual process models of recognition. Of particular relevance to this thesis, in providing an outline of functional neuroimaging findings which address some of the issues relating to models of recognition memory, the use of event-related measures of brain activity in memory research has also been introduced. The following chapters will, more specifically, consider how the employment of event-related potentials (ERPs) may further

elucidate cognitive processes underlying recognition. Before reviewing findings from studies that have employed ERPs to investigate recognition memory (Chapter 3), issues relating to ERP methodology will first be discussed.

CHAPTER 2

Event-related potentials (ERPs)

ERPs and cognitive psychology

The exclusive use of behavioural measures for memory research can provide only limited insights into the cognitive processes supporting memory performance. This is because behavioural measures do not provide direct access to the neural events thought to instantiate cognitive processing and can index only the output of these processes. The employment of electrophysiological techniques, however, provides more direct information with regard to the associated neural activity by measuring electrical brain activity elicited during the performance of specific cognitive tasks. Assuming that these measures do, in fact, reflect cognitive processing, when neural activity is assessed in relation to specific experimental manipulations, theories of cognition may be constrained in a number of ways that would not be possible with behavioural measures alone.

Event-related potentials (ERPs) can provide a non-invasive method of recording changes in the brain's electrical activity that are associated with a specific event such as the presentation of a word. ERPs are extracted from the electroencephalogram (EEG), the latter being a measure of the overall electrical activity occurring spontaneously within the brain. The human EEG is usually recorded via scalp electrodes and reveals a pattern of voltage fluctuations over time. ERPs index discrete epochs taken from the ongoing EEG which are time-locked to an external stimulus event to provide information regarding the time course, frequency and scalp distribution of the associated neural activity. Signals

from these epochs are averaged across multiple trials relating to a specific class of experimental stimuli to produce the resulting ERP waveform. As this process of averaging occurs subsequent to EEG recording, ERP waveforms can also be formed *post hoc* according to behavioural measures. In this way, it is possible to contrast differential neural activity elicited by items from the same experimental class depending on whether they attract a correct or an incorrect behavioural response.

In the area of human memory, ERPs are a particularly useful research tool as they provide an alternative means to separate and identify different stages and types of memory processing when overt behavioural measures for such investigations cannot be obtained. Typically, ERPs have been recorded at various stages of memory processing in order to identify at what point specific experimental manipulations exert their effects. For example, ERPs have been employed to determine whether directed forgetting instructions influence processing at the stage of encoding and/or retrieval (Paller, 1990; Ullsperger, Mecklinger & Muller, 2000). ERPs can also be employed to examine particular types of memory processes that do not elicit direct behavioural responses, such as those underlying implicit memory (Rugg *et al.*, 1998). With this type of application, the benefits obtained with ERP methods are similar to those achieved with other functional neuroimaging techniques such as functional magnetic resonance imaging (fMRI) which provides haemodynamic measures of brain activity. However, as each type of neuroimaging technique is associated with a unique set of strengths and weaknesses, together, they can provide complementary perspectives on the functional and physiological bases of cognitive processing.

In comparison to ERPs, haemodynamic methods provide greater spatial information regarding the locus at which processing takes place. In contrast, it is not possible to specify the exact location of the neural generators that give rise to ERPs without the use of other constraining sources of information. This is because there is no unique solution to the 'inverse problem' of determining the number and location of internal sources for any one particular pattern of electrical activity that may be recorded at the scalp. The strength of the ERP technique, however, lies in its superior temporal resolution (in the order of milliseconds), which, unlike the haemodynamic techniques, allows processing-related neural activity to be monitored in real time. Therefore, by identifying at what point in time differences in neural activity occur between conditions, ERPs can provide important constraints regarding the time-course of specific types of processing. In this way, ERPs can also be used to separate and identify neural activity associated with particular cognitive processes based partly on what is known about their relative time courses. In recognition tasks, for example, neural activity associated with familiarity processing might be expected to emerge at an earlier time point than that relating to processes of recollection.

It is important to note, however, that, while differences in ERPs can place an *upper* limit on the time by which processing differs between conditions, they cannot rule out the possibility that differences in processing may have occurred at an earlier time point (Rugg & Coles, 1995). It is quite possible, for example, that earlier ERP differences may have been of too small an amplitude to be registered at the scalp. Furthermore, as it is only the electrical activity generated by neurons of specific configurations and orientations in the brain that can be detected at the

scalp, possible ERP differences may not always be apparent. These points illustrate a more general constraint relating to the interpretation of all functional neuroimaging data, in that, while positive findings of differential neural activity provide support for differences in cognitive processing, strong conclusions cannot be drawn on the basis of null findings. In order to more fully appreciate these and other caveats relating to the use and interpretation of ERPs, it is necessary to have some understanding of their neural origins, to be outlined in the next section, 'electrogenesis'. This will be followed by an introduction to a number of topics relating to ERP methodology, including the recording, analysis and interpretation of ERP data, to provide a basic overview of the principles underlying ERP research.

Electrogenesis

ERPs are a measure of voltage fluctuating over time, produced by ionic current flow across the membranes of active neurons. It is thought that scalp-recorded ERPs mainly reflect the graded response of inhibitory and excitatory post-synaptic potentials, generated at the dendrites of pyramidal cells, rather than the all-or-none response of axonal action potentials (Allison, Wood & McCarthy, 1986). In order to produce activity of sufficient magnitude to be detectable at the scalp, large populations of such cells are required to fire in synchrony. When these neurons are oriented in parallel and in the same direction, their summated potentials generate an 'open field' in extracellular space which can be measured at some distance from its source (see figure 2.1). This field can be represented as a single dipole consisting, as it does, of current flowing between positive and negative charges (Kutas & Dale, 1997). Furthermore, if the arrangement of neurons

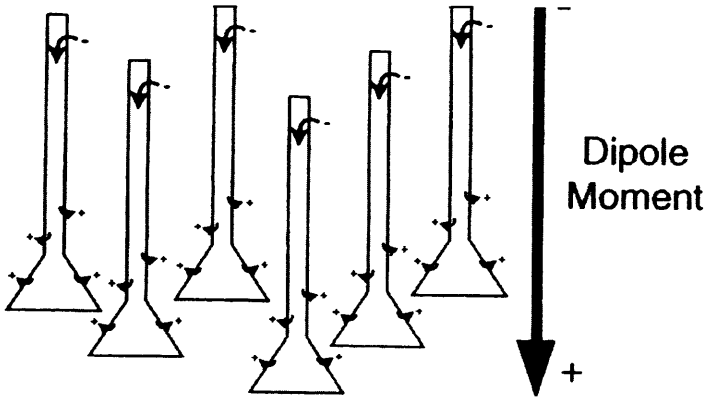

Figure 2.1. Open field source configuration. Adapted from Kutas and Dale (1997).

generating this field is roughly perpendicular to the cortical surface, the current may propagate through the conductive tissue of the brain and surrounding areas to the surface of the scalp.

A 'closed field', in contrast, is created by neurons that are organised in such a way that their activity cannot be measured outside of the field (see figure 2.2). Neurons generating closed fields typically fire asynchronously, or are oriented in different directions such that potentials from individual neurons cancel each other out. Alternatively, they may be arranged with dendrites radiating outwards, as is the case with stellate cells, resulting in a net current flowing inwards. As each of these neuronal configurations leads to an extracellular potential of zero, activity from such fields could not contribute to scalp-recorded ERPs. Given these constraints, it would seem that only a proportion of the brain's total activity could ever reach the scalp. Neural activity that satisfies the necessary requirements to be recorded at the scalp tends to be generated by neurons from areas exhibiting a laminar structure, such as the neocortex, where large numbers of pyramidal cells are found. In contrast, the configuration of neurons in other brain structures, such as the thalamus, are unlikely to produce any detectable activity outside the field or,

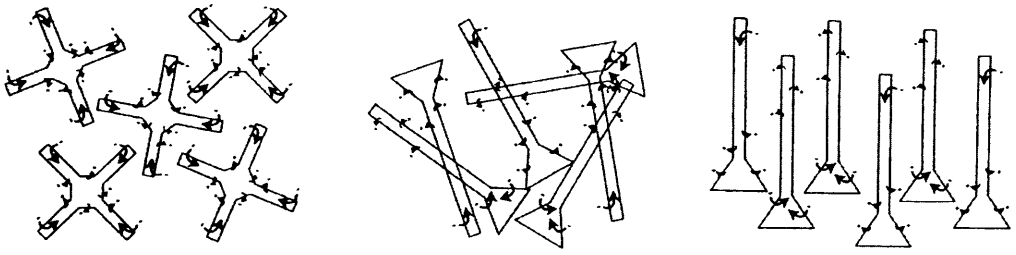

Figure 2.2. Examples of self-cancelling or closed field source configurations. Adapted from Kutas and Dale (1997).

therefore, at the scalp (Coles & Rugg, 1995).

The effects of different neuronal configurations have important implications for the interpretation of ERP data as the absence of any ERP effects may simply be due to neural activity occurring in closed, rather than open, fields. Also, because of the conductive media of the brain and surrounding tissue, the magnitude of scalp-recorded ERPs is governed by the laws and principles of volume conduction. Given that neural tissue and the skull act as low-pass filters, a field current will diminish with increasing distance from the neuronal source and will be visible over relatively broad areas of the scalp. Finally, scalp-recorded ERPs do not generally reflect activity from a single field potential, but are more likely to index potentials from multiple open fields. As open field currents pass through the brain, surrounding tissue and scalp, they linearly summate with one another. The resulting scalp-recorded ERPs will, therefore, reflect the linear summation of fields that have been generated in multiple brain regions.

ERP recording

For the recording, a number of electrodes must be attached to the scalp, along with an electrolyte solution, so that a connection between the participant and the recording equipment can be made. The quality of the recording will depend upon the type of electrodes used, as well as the integrity of the connection between the electrodes and the skin. The immersion of a metal electrode into electrolyte solution can create an 'electrical double layer' of oppositely charged ions. This will cause the electrode-skin interface to act as a high-pass filter which may distort the recorded signals. It is, therefore, standard practice to employ 'reversible' electrodes, such as those made of silver/silver chloride (Ag/AgCl), which will eliminate the electrical double layer (Picton, Lins & Scherg, 1995). The conductivity of the electrode-scalp connection is also important in assuring high quality data. The impedance of the electrode-skin interface should be small in relation to the input impedance of the amplifier and can be decreased by abrading the scalp beneath the electrodes. Typically, this impedance is kept below 5 kΩ. Electrodes are positioned according to standard scalp locations to allow easy comparisons between ERP experiments. The specific number and location of recording sites will depend on the particular aim and/or area of research. For example, it is necessary to employ a fairly dense array of electrodes in order to plot the scalp distribution of ERPs. In general, though, there should be an even distribution of electrodes over multiple scalp locations which, typically, includes mid-line and lateral sites.

While scalp electrodes are certainly sensitive to field potentials derived from the brain, they will also pick up electrical activity from a number of external

sources – for example, activity from electrical equipment such as the display monitor. As scalp-recorded neural activity is generally much smaller in magnitude than the electrical activity picked up from the environment, it is important to remove this environmental 'noise'. This can be achieved with the use of differential amplifiers which cancel out any activity that is common to all scalp electrodes from the array (known as 'common mode activity'). When using a 'referential' montage, each electrode from the array is connected to the same 'reference' electrode, which should be located at a site at which there is relatively little electrical activity of experimental interest (Coles & Rugg, 1995). This common reference could be a single electrode located, say, at the nose tip, or a pair of 'linked' electrodes, such as those placed over the mastoid processes, which provide a combination of the activity found at the two electrode sites. In both cases, the resulting measurement reflects the difference in voltage between that obtained at each individual electrode site and the common reference site. Therefore, while the choice of reference site will influence the absolute value and/or polarity of these potential differences, the profile of effects across the scalp will remain the same.

Although these 'differential' measures are initially recorded as continuous analogue signals, they are sampled at discrete time intervals and amplified to a range that will ultimately allow accurate conversion to digital signals. The rate of conversion (samples per second) determines the temporal resolution of the ERP data. However, this sampling rate needs to be at least twice the highest frequency present in the signal (i.e., the 'Nyquist' rate). When frequencies higher than half the sampling rate (i.e., the Nyquist frequency) enter into the conversion, they may appear in the digitised data under the 'alias' of their lower harmonics (Picton *et al.*,

1995). During amplification, the analogue signals are filtered in order to reject any high frequencies that may cause aliasing of the data, as well as any low frequencies that might cause the amplified signal to exceed the amplitude range ('block') of the analogue-to-digital converter.

Extracting the signal

The digitised data contain both the signal of interest (i.e., the ERPs) as well as the background 'noise', consisting of the ongoing EEG together with various non-neural artefacts. As the signal is generally much smaller than the noise, the 'signal-to-noise' ratio must be increased so that the ERPs can be measured and analysed. The signal is extracted from the noise through the process of 'signal averaging'. This involves recording repeated epochs of EEG that are time-locked to a stimulus event of the same experimental class. Averaging is performed on the digital EEG data at each time-point in the epoch to reveal a single set of values representing the mean activity at each of these points (Coles & Rugg, 1995). It is assumed that the signal remains constant across trials (epochs) of the same class, and that the noise is random and uncorrelated with the signal. If these assumptions are met, signal averaging will reduce the influence of noise in proportion to the event-related activity. This signal-to-noise ratio improves as a function of the square root of the number of trials used for averaging (Picton *et al.*, 1995).

However, not all noise can be reduced through averaging. This includes non-neural artefacts that are time-locked to the stimulus event which, when averaged, will overlap and contaminate the neural ERP. As the process of averaging requires the background noise to be of similar form from trial to trial, artefacts that produce particularly large signals in a small number of trials will also

be problematic (Picton *et al.*, 1995). These non-neural artefacts can take the form of baseline drifts, muscular activity and eye movements, and these should be rejected prior to averaging. The concurrent recording of the electro-oculogram (EOG) allows trials with saccadic eye movements and blink artefacts to be monitored and removed. Alternatively, the contribution of blink-related artefacts to all other recording channels can be estimated for each participant and algorithmically corrected. Digital filtering is also usually applied in order to reject any frequencies that are unlikely to reflect the activity of interest, such as the high frequencies attributable to muscular activity. Digital filtering can occur either before or after averaging in order to further improve the signal-to-noise ratio.

It is important to interpret averaged ERPs with caution as signal averaging may produce ERP waveforms that bear little relation to the signal that was originally present on individual trials. This might well be the case when there is variability from trial to trial in either the latency or amplitude of a particular ERP component, leading to a 'smearing' of the averaged waveform (Picton *et al.*, 1995). For example, when an ERP component differs in magnitude between two conditions, this would generally be interpreted as a graded difference in amplitude that would be occurring on individual trials. Alternatively, it could be that it is the proportion of trials for which this component occurs that differs between the two conditions, leading to overall differences in amplitude. A third interpretation may arise if, for one condition, there was greater variability in the latency of the component from trial to trial (i.e., 'latency jitter'), leading to an average ERP component with decreased amplitude and long duration.

Measuring ERP components

Average ERP waveforms contain a number of positive and negative peaks which are generally described in terms of their polarity, latency (in msec), amplitude (in μV) and scalp distribution. While measures of latency reflect the temporal relationship between such peaks and presentation of the external stimulus, amplitude is usually measured in relation to a pre-stimulus baseline (i.e., the mean amplitude over a period of time preceding stimulus presentation). Traditionally, each peak was associated with a single ERP component and labelled in terms of its polarity and peak latency (e.g., 'P300' describes a positive peak with a maximum amplitude at around 300 msec post-stimulus). It is generally agreed that an ERP component represents the activity of a group of neurons associated with a specific processing operation. These components can be 'exogenous' or 'endogenous'. While exogenous components are sensitive to the physical properties of the external stimulus, endogenous components are associated with the psychological events resulting from the presented stimulus. However, there are difficulties in trying to identify a particular ERP component with a specific peak from the waveform. This is because voltage measured at the scalp will reflect the summated activity from a number of different sources in the brain. Given that these may have different time courses, each peak is likely to reflect a number of different ERP components that overlap both spatially and temporally.

Such ambiguity in interpreting peaks in ERP waveforms has led to the proposal that the term 'component' should be reserved for those features of the waveform that can be attributed to the activity of specific neuronal populations. This view is in line with a 'physiological approach' which characterises ERP

components in terms of their neural generators, but with little attempt to ascribe cognitive functions to these components. Given the difficulties in determining the number and location of neural generators from scalp-recorded ERPs (as described by the 'inverse problem'), this approach is limited, although a number of techniques have been used to attempt to identify their source. A common method to infer sources directly from scalp-recorded ERPs is the Brain Electrical Source Analysis (BESA) procedure (Scherg, 1990). This analysis postulates a set of distinct sources, described in terms of 'equivalent dipoles', that remain constant in location and orientation during recording. These are modelled in terms of how their contribution to the ERP waveform varies over time. The locations and orientations of sources are then fit to the data by determining the similarity between the modelled waveforms and the actual waveforms recorded at the scalp. As multiple solutions are usually generated by BESA, knowledge derived from other methods such as intracranial recordings, lesion studies and haemodynamic techniques can both aid in identifying neural generators, as well as constrain their likely number and location.

A more simple solution to increasing the spatial resolution of ERPs and identifying the source of their components is to employ a greater number of electrodes in the recording array. However, it has been argued that, in order to provide enough spatial information to distinguish the scalp effects of discrete cortical generators, it would be necessary to employ over 100 recording channels (Gevins, Leong, Smith, Le & Du, 1995). Also, because of the effects of volume conduction, the field currents distort as they propagate through the brain tissue and scalp, smearing any spatial separation between their sources. The scalp distribution

of ERP effects can also be represented with topographic maps which show the positions of maximum and minimum amplitudes across the scalp, in a similar way to contour maps of terrain. This mapping requires three-dimensional data to be plotted as a two-dimensional representation, and data between recording sites must be interpolated from the available information. Although purely descriptive, this technique can be used to highlight any differences in the scalp distribution of ERP effects between experimental conditions.

In contrast to the physiological approach, the psychological approach aims to identify the variations in ERPs which are associated with specific cognitive functions rather than neural generators. With this approach, an ERP component is defined in terms of a specific feature of the waveform that is correlated with a particular psychological process (Coles & Rugg, 1995). If, as is likely, different processing operations occur in parallel, each component will reflect more than one cognitive process. Therefore, in order to isolate unique components, waveforms from different experimental conditions are subtracted from one another. Any ensuing difference (e.g., in terms of amplitude) is defined as the component of interest and identified with the particular cognitive process thought to differ between the conditions. Such functional interpretations of ERP effects can be facilitated with behavioural data and require a theoretical understanding of the cognitive significance of experimental manipulations. One challenge for the subtraction procedure is that it must rest on the assumption of 'pure insertion'. In the context of ERPs, this refers to the assumption that the experimental conditions used to identify an ERP component differ only with regard to the cognitive process

of interest but are equivalent with respect to all other processes (for a critique of pure insertion and the subtraction method, see Friston *et al.*, 1996).

While the physiological approach to component definition attributes differences in ERP voltage across the scalp to differences in source location, the psychological approach ascribes variations in voltage as a function of experimental manipulations to variations in cognitive processes. Ultimately, however, the interpretation of ERPs needs to be aimed at understanding both their functional and their physiological significance. Indeed, analytical techniques have been developed to extract ERP components which encompass features of both physiological and psychological approaches (Coles & Rugg, 1995). For example, Principal Components Analysis (PCA) is a method used to identify patterns of co-variation in ERP data sets. Such data comprise values representing temporal and topographic changes in voltage, as well as changes in voltage associated with experimental manipulations. When applied to an ERP data set, PCA yields a set of 'components' which are weighted for each time-point in the epoch, indicating to what degree each component is present in the waveform. Once identified, these patterns of co-variation (or components) need to be interpreted, and this is usually achieved with reference to the component's polarity, latency and distribution across the scalp, as well as to its sensitivity to experimental manipulations.

However, there are a number of reasons to be cautious when interpreting the results of PCA. For example, PCA has been shown to 'misallocate' variance between extracted components, partly due to noise in the data (Wood & McCarthy, 1984). Also, components contributing only small amounts of variance during experimental manipulations may not always show up clearly in the analysis. In

contrast, when different experimental conditions elicit the same component but at different latencies, spurious components can be identified (Coles & Rugg, 1995). An alternative method to PCA is to take the mean amplitude of the waveform across a specified latency region. This approach removes the focus away from the significance of specific peaks and employs the subtraction procedure to consider how mean amplitudes differ between conditions. Mean amplitude measurements reduce the problem of latency variance between conditions and also have the advantage of being more resistant to noise than those of individual peaks. While it is important that particular latency regions capture the main effect of interest, these should be specified *a priori* on the basis of previous studies.

Inferences from ERP data

It is generally assumed that ERPs represent some aspect of brain activity and that this activity is associated with specific cognitive processing. In order to make functional inferences from ERP data, however, it must be assumed that the relationship between cognitive processes and their associated neural activity is invariant. Given this assumption, any difference in the ERPs from different experimental conditions can be identified with specific types of cognitive processing thought to differentiate the conditions. Such differences between the waveforms may be tested for significance using inferential statistics, such as Analysis of Variance.

Reliable differences between ERPs can indicate that cognitive processes differ either quantitatively or qualitatively. Quantitative differences are demonstrated when there are differences in amplitude between ERPs which have equivalent scalp distributions. This type of difference is thought to indicate the

engagement of similar brain regions which are differentially activated. In functional terms, this might indicate that similar cognitive processes are engaged in each condition, but that there are experimentally induced quantitative differences in the activity of the underlying neural generators. Such modulations could arise either from changes in the number of activated neurons within the generator, or changes in the number of cells firing in synchrony. The greater the number of active and/or synchronous cells, the greater the amplitude of the ERPs. However, care must be taken to ensure that any differences between conditions in the amplitude of ERPs cannot be accounted for by latency jitter. As mentioned previously, when there is greater variability in the latency of a component across individual trials, this may give rise to the temporal smearing of an average ERP component which is reduced in amplitude but of greater duration. A qualitative difference is indicated by differences in scalp distribution between ERPs. Such 'topographic' differences suggest the engagement of different brain regions. Functionally, these qualitative differences reflect the engagement of distinct cognitive processes. It should be noted that reliable qualitative differences may arise, not only between experimental conditions, but also across latency regions within a single experimental condition.

As noted previously, when interpreting ERP data, although reliable findings of differential neural activity across conditions provide support for differences in cognitive processing, strong conclusions cannot be drawn on the basis of null findings. For example, an alternative possibility is that potential differences in ERPs may be of too small an amplitude to be registered at the scalp. Also, as it is only the electrical activity generated by neurons of specific configurations and

orientations in the brain that can be detected at the scalp, potential ERP differences may not always be apparent. Finally, it must be noted that, as with all neuroimaging data, ERPs are purely correlational in nature. It is, therefore, not possible to establish causal relationships between cognitive processes and neural activity with the use of ERPs alone.

CHAPTER 3

ERP Studies of Recognition Memory

This chapter provides a selective review of ERP studies investigating recognition memory to show how this technique can provide a unique approach to investigating memory processes and to provide a background for the research reported in this thesis. The studies to be reviewed are those that have provided insights into the neural correlates of processes associated with the recovery and representation of retrieved information and the evaluation of such information (or the absence of such information). Although retrieval cues associated with both 'old' and 'new' items in a recognition test should elicit neural activity correlated with processes subserving a retrieval attempt, relative to 'old' retrieval cues, 'new' retrieval cues should be associated with minimal successful retrieval of episodic information (Rugg & Wilding, 2000). Therefore, activity subserving successful retrieval is thought to be revealed by comparisons between activity elicited by unstudied retrieval cues relative to activity elicited by studied retrieval cues (e.g., old versus new words in a recognition memory task).

ERP correlates of recognition memory

Early ERP studies generally employed one of two paradigms to investigate recognition memory: 1) continuous recognition required participants to identify which of a continuously presented succession of items were repeated; 2) in the study-test paradigm, participants were first presented with a list of study items and, after a break of variable length, were asked to identify which items had, and which had not, been studied from a test list consisting of both studied and new items.

Repeated and studied items were designated as 'old' and all other items were designated as 'new'. These studies consistently reported that ERP activity was more positive when elicited by correctly identified old items than for items correctly judged as new (e.g., Neville, Kutas, Chesney & Schmidt, 1986; Friedman, 1990; Rugg, Brovedani & Doyle, 1992; Rugg & Doyle, 1992). This effect onset at approximately 400 msec post-stimulus, continued for another 400-600 msec, and was maximal over parietal sites. Originally, this effect was termed the 'late positive component' and tended to be bilaterally distributed, particularly in tests of continuous recognition (e.g., Rugg *et al.*, 1992). However, in study-test paradigms employing verbal stimuli, this effect tended to be left lateralised (see figure 3.1) and became known as the 'left parietal old/new effect' (e.g., Allan & Rugg, 1997).

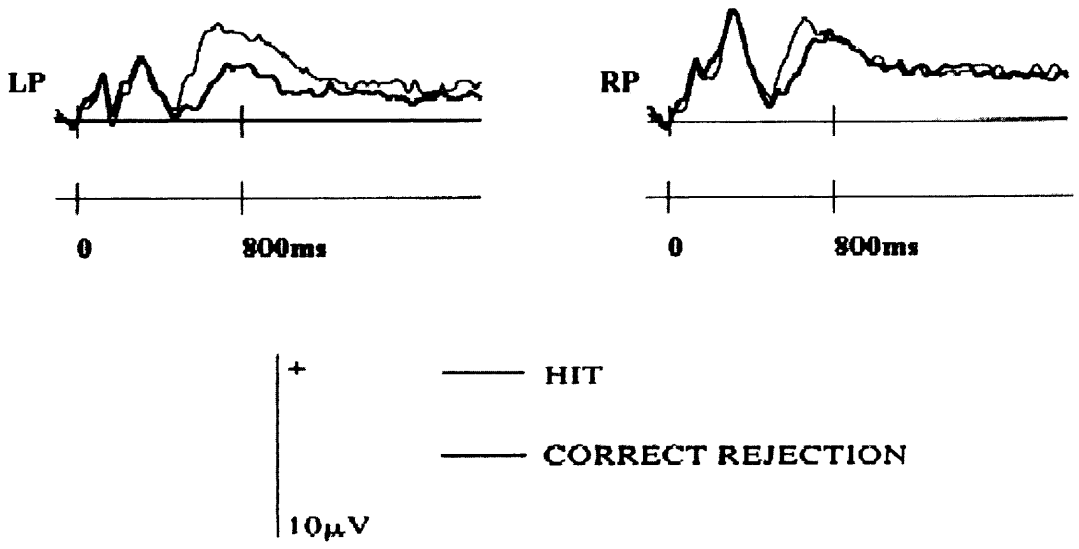

Figure 3.1: The 'left parietal old/new ERP effect'. ERPs elicited by correctly classified old and new words over left and right parietal (LP, RP) electrode sites. Data from Allan and Rugg (1997).

The parietal effect was initially identified with the P3b subcomponent of the well-established P3 which has been thought to reflect context updating in working memory. Specifically, it was argued that the parietal effect perhaps reflected the fact that old words in recognition tests have lower subjective probability and higher 'targetness' than new words (Neville *et al.*, 1986). To investigate this possibility, Smith and Guster (1993) recorded ERPs during a recognition memory task in which 'target' words, which were old or new words according to the stimulus set, were rare events. Participants were required to respond with a key press only to those items designated as targets. This design allowed any effects of response, 'targetness' or subjective probability to be distinguished from mnemonic effects. If the parietal effect merely reflected responses to targets with low subjective probability, then there should be no difference between ERPs to old targets and those to new targets. However, as there was a difference between these two item types, the parietal effect was identified as a mnemonic retrieval-related component (Smith & Guster, 1993). Furthermore, as it was also found that the parietal old/new effect was not elicited by old items incorrectly judged as new ('misses') or by new items incorrectly endorsed as old ('false alarms') (Rugg & Doyle, 1992; Rugg & Doyle, 1994), it seemed that, rather than simply being related to item repetition or positive responses, this effect reflected veridical recognition judgements.

Investigations then concentrated on questions regarding the functional significance of this ERP old/new effect, particularly in the context of dual-process models of recognition. Initially, it was suggested that the effect was a correlate of familiarity-based recognition when it was discovered that low-frequency words elicited a larger old/new effect than that elicited by high-frequency words (Rugg &

Doyle, 1992). This interpretation was based on findings that recognition performance is better for low frequency words than for high frequency words, the so called 'word frequency effect' (Glanzer & Bowles, 1976), which had been accounted for by an increase in the relative familiarity to low frequency items (Jacoby & Dallas, 1981; Mandler, 1980). However, it since became apparent that the word frequency effect was, in fact, mainly attributable to the superior recollection of low-frequency words (Guttentag & Carroll, 1994). Furthermore, a number of ERP studies reported evidence of an association between the left parietal effect and recollection (e.g., Smith, 1993; Wilding, Doyle & Rugg, 1995). Smith (1993) used the remember / know procedure alongside ERP measures and found larger old/new effects for 'remember' responses in comparison to 'know' responses. Smith (1993) suggested that these findings indicated that the parietal old/new effect was associated with processes underlying recollection. Furthermore, an ERP experiment using identification of study modality as a measure of source memory (Wilding *et al.*, 1995) found a left parietal old/new effect for items correctly judged to be old, but not for those old items for which the study modality had been incorrectly assigned. Therefore, it appeared that the left parietal old/new ERP effect was closely associated with recollection. Further support for this hypothesis come from ERP studies investigating false recollection (e.g., Duzel, Yonelinas, Mangun, Heinze & Tulving, 1997). This term relates to the false alarms made by participants when endorsing unstudied associates of studied items as having been 'remembered'. It has been proposed that this type of response depends upon the same processes that support true recollection (Schacter *et al.*, 1996). Duzel *et al.* (1997) found that ERPs elicited by falsely recollected items, in contrast

to false alarms that were not associates of the study words, elicited left parietal old/new effects comparable to those elicited by correctly recognised old items.

Further work revealed other ERP correlates of recognition memory which appeared to be neurally and, therefore, functionally dissociated from the left parietal old/new effect. These effects were largely interpreted within the framework of dual-process models.

Fractionating ERP correlates of recognition memory

Various paradigms known to have dissociative effects on familiarity and recollection have been employed by studies investigating ERP correlates of recognition memory. These include the remember / know paradigm, the exclusion task from the PDP and source memory tasks in which ERPs for correctly identified old items are separated according to whether their source is correctly or incorrectly specified. Although, as mentioned previously, processes of recollection are assumed to be engaged when contextual information from study ('source') is accurately retrieved, it is less certain as to whether this manipulation can, in fact, truly isolate recollection from familiarity. One ERP study (Wilding & Rugg, 1996) which employed a source memory task (male vs. female voice), found ERPs to be more positive for correctly recognised old words than correctly rejected new words. Although quantitative differences were reported between ERP old/new effects for items associated with correct, as opposed to incorrect, source identification, there were no reported differences in their scalp distributions. Although these ERP old/new effects were assumed to be associated with processes of recollection and familiarity, respectively, it could not be demonstrated that these were functionally dissociable in this experiment. Therefore, these findings offered

little support for the view that recognition with and without the retrieval of source information engage different cognitive processes and suggested that the difference between familiarity and recollection may be one of degree rather than of kind.

Nevertheless, this was one of the first studies to provide evidence of a second old/new effect that could be dissociated from the left parietal old/new effect in terms of its time course as well as its scalp distribution (see figure 3.2). This second effect onset at a similar latency to the left parietal old/new effect but was more sustained in time and maximal over right frontal sites. This 'right frontal old/new effect' was greater in magnitude for items associated with correct, in comparison to incorrect, source identification. Wilding and Rugg (1996) interpreted the right frontal effect as reflecting 'post-retrieval' operations – i.e.,

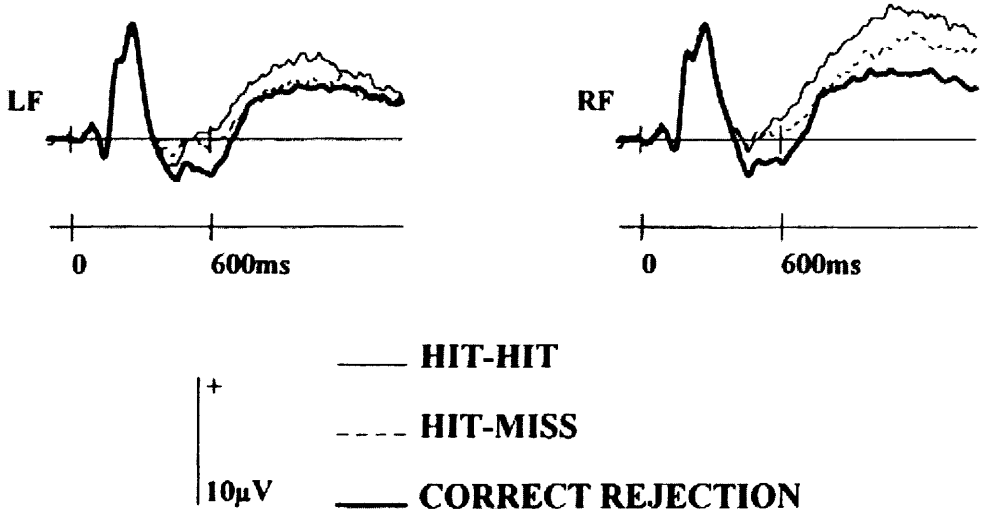

Figure 3.2: The 'right frontal old/new effect'. ERPs from left and right frontal (LF, RF) electrodes. Hit-Hit: denotes recognised old items for which source was correctly assigned; Hit-Miss: denotes recognised old items for which source was incorrectly assigned. Data from experiment 2 of Wilding and Rugg (1996).

processes acting on the products of retrieval in order to generate an episodic representation to support accurate source discrimination. Wilding and Rugg (1997) conducted another study to investigate whether the right frontal old/new effect could be generalised to other paradigms. They employed an exclusion task similar to that used in the PDP (Yonelinas & Jacoby, 1994). Words were presented at study spoken in either a male or female voice and participants were required to perform different encoding tasks for each word depending on which voice they heard. This experiment differed from typical exclusion tasks in that the encoding manipulation was intermixed within one list rather than blocked across two lists. At test, words were presented visually and participants were required to respond 'old' to items presented in a specific voice at study ('targets') and to respond 'new' to all other words including new words and words spoken in the alternative voice at study ('non-targets'). As reviewed in Chapter 1, in order to discriminate the two classes of studied words, given that they should attract equal levels of familiarity, recollection of source would be necessary for accurate performance. A left-lateralised parietal old/new effect was found for both classes of studied item, although the effect was smaller for non-targets. However, a right frontal old/new effect was found for targets only. Furthermore, ERPs elicited by non-targets and new words misclassified as targets showed no evidence of right frontal or left parietal old/new effects. According to the PDP, these items would have been misclassified due to high levels of familiarity but low levels of recollection. Therefore, this study provided further evidence that the left parietal old/new effect is related to recollection and that the left parietal and right frontal old/new effects are functionally dissociable.

The finding that non-targets, having been successfully excluded, did not elicit a right frontal old/new effect, led Wilding and Rugg (1997) to suggest that this right frontal old/new effect, while being related to recollection, may be more closely tied with strategic processing which varies with task demands. Conclusions consistent with Wilding and Rugg's (1997) were drawn from another ERP study (Senkfor & Van Petten, 1998) comparing recognition performance for spoken words across two tasks, one task requiring simple item recognition and the other requiring correct source (voice) identification. The frontal effect in this experiment, which was bilaterally distributed over prefrontal regions, was found only for the task requiring source judgements and this effect did not vary according to source identification accuracy. It was suggested that this prefrontal activity reflects search processes which attempt to link items with their source during retrieval (Senkfor & Van Petten, 1998). An alternative view regarding the functional significance of the right frontal effect was proposed based on findings from an ERP study that varied depth of processing at study (Rugg, Allan & Birch, 2000). While a larger left parietal old/new effect was found for deeply- compared to shallowly-encoded words, a right frontal old/new effect was elicited only by shallowly-encoded words. As responses to deeply-encoded words were faster and more accurate than those to shallowly-encoded words, it was pointed out that shallowly-encoded words were likely to have been judged with lower confidence than deeply-encoded words (Rugg *et al.*, 2000). As such, the identification of shallowly-encoded words might well have engendered a greater degree of monitoring and evaluation during test and, therefore, it was suggested that the right frontal effect may be related to the strategic monitoring and evaluation of the products of a retrieval *attempt* (Rugg *et*

al., 2000) In addition to this observation, these findings further suggest that recollection is neither necessary nor sufficient to elicit the right frontal old/new effect (Rugg *et al.*, 2000).

The studies reviewed so far provide some evidence that the left parietal old/new effect is a neural correlate of recollection and that this effect is functionally dissociable from a right frontal old/new effect. However, little evidence had been provided to support dual-process models of recognition as none of the studies reviewed above reported qualitatively distinct ERPs associated with familiarity-based versus recollection-based recognition. More recently, though, a number of ERP studies have shown evidence for the dissociable neural correlates of familiarity and recollection (e.g., Curran, 2000; Friedman & Johnson, 2000; Rugg *et al.*, 1998). Rugg *et al.* (1998) reported greater negativity for correctly rejected new words in comparison to recognised old words at frontal sites with a latency range of 300-500 msec (see figure 3.3). This early frontal effect differed qualitatively from a later onsetting left-lateralised parietal old/new effect. It was proposed that the early frontal effect, being insensitive to a depth of processing manipulation at study but, importantly, predictive of recognition accuracy, reflected familiarity-based recognition whereas the left parietal effect, being larger for deeply-encoded items than for shallowly-encoded items, reflected recollection. Furthermore, this study also identified a neural correlate of implicit memory which dissociated from the early frontal effect thought to reflect familiarity. The processes contributing to implicit memory have often been identified with those contributing to familiarity-based recognition in terms of the ease with which

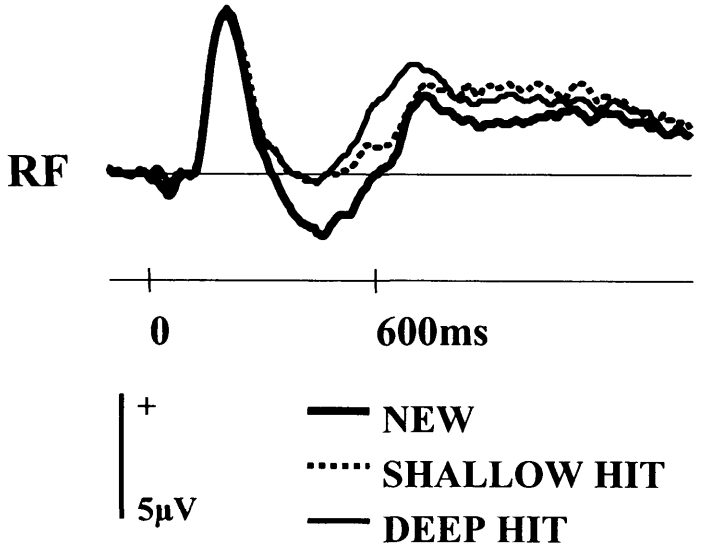

Figure 3.3: 'Early frontal old/new effect' ERPs from right frontal electrode. SHALLOW: denotes correctly classified shallowly studied items; DEEP: denotes correctly classified deeply studied items; NEW: denotes correctly classified new items. Data from Rugg *et al.* (1998).

repeated items may be processed. However, Kelley and Jacoby (1993) have proposed that a distinguishing feature of familiarity is the phenomenal experience, engendered by *unconscious* attributions of processing fluency, of having been recently experienced. In Rugg *et al.'s* (1998) study, an ERP old/new effect was found during the same latency range as the early frontal effect but located at parietal sites. This latter effect was insensitive to both the depth of processing manipulation and to recognition accuracy as it was elicited for all old items regardless of identification accuracy. Therefore, it was argued that the early parietal effect is a neural correlate of memory in the absence of conscious recognition.

Some evidence indicating that depth of processing may not reliably dissociate recollection from familiarity (Toth, 1996; Yonelinas *et al., 1998*) casts some doubt on Rugg *et al.'s* (1998) conclusions regarding the functional dissociation between familiarity and recollection. However, other studies using different manipulations have shown similar findings. Curran (2000) conducted a

study in which study words were presented either in the same or reversed plurality at test. Participants were required to respond 'yes' to items presented in the same plurality and 'no' to items presented in the reversed plurality as well as to new items. This study was based on a behavioural experiment (Hintzman & Curran, 1997) which used a response-signal technique (Dosher, 1984) to study the temporal dynamics of memory retrieval. Hintzman and Curran (1997) estimated the time course of memory retrieval by tracking accuracy increases over time and found that participants were able to discriminate old from new items at around 420 msec but could not make this discrimination for studied and plurality-reversed words until around 540 msec. As studied and similar words should be more familiar than new words but recollection would be necessary to discriminate between studied and similar words, it was suggested that familiarity influenced recognition judgements around 120 msec prior to plurality recollection (Hintzman & Curran, 1997). The ERP study found a parietal old/new effect, with a latency range of 400-800 msec, for correctly identified old words only. However, an early frontal effect was also found, with a latency range of 300-500 msec, with ERPs to correctly rejected new items being more negative than those to both studied and incorrectly endorsed plurality-reversed items. This effect was found to be left-lateralised and maximal over frontal sites. It was suggested that, as incorrectly endorsed plurality-reversed items are likely to reflect familiarity in the absence of recollection, the early frontal effect reflected familiarity-based recognition. The fact that the early frontal effect preceded the parietal old/new effect by approximately 100 msec was consistent with behavioural findings that familiarity is faster-acting than recollection. Furthermore, the finding that the scalp distributions associated with the two effects

were qualitatively distinct suggests that recognition does, in fact, comprise two distinct cognitive processes related to familiarity and recollection.

Neuropsychological studies investigating ERP correlates of recognition memory have provided further support for the above conclusions (Tendolkar *et al.*, 1999; Duzel *et al.*, 1997). In the study by Tendolkar *et al.* (1999), ERPs were recorded from patients with Alzheimer's Disease as well as from controls. Participants were required to complete an old/new recognition task and, for those items identified as 'old', participants were also required to complete a source memory task - i.e., naming which colour each item had been presented in at study. Both controls and Alzheimer's patients showed recognition performance to be above chance, although Alzheimer's patients were severely impaired in their performance for the source memory task. The control group showed old/new ERP effects over frontal (300-500 msec) and left parietal sites (300-900 msec), with larger old/new effects over the left parietal sites when these were associated with correct, as opposed to incorrect, source identification. In contrast, for the Alzheimer's group, old/new ERP effects were only elicited at frontal sites at a latency range of 300-500 msec. Considering the Alzheimer's patients could not accurately retrieve source information, the authors proposed that their relatively preserved recognition performance is familiarity-based and independent of recollection. Therefore, it was concluded that the early frontal and left parietal effects reflected recognition memory based on familiarity and recollection respectively. Duzel *et al.* (2001) recorded ERPs during a recognition task from an amnesic patient (Jon) and normal controls. Although Jon suffered early hippocampal damage, he showed recognition performance that, while being below

that of the controls, was, nevertheless, above chance. Early (300-500 msec) frontally distributed and later (500-700 msec) parietal old/new effects were elicited for control participants while only the early frontal old/new effect was apparent for Jon. Similar conclusions were drawn to those in Tendolkar *et al.*'s (1999) study – while controls were able to recognise test items based on familiarity as well as recollection, Jon relied exclusively on familiarity. Furthermore, the early frontal old/new effect was proposed to reflect familiarity-based recognition while the later parietal effect was associated with recollection. Therefore, the more recent studies reviewed above seem to support dual-process models of recognition memory. A summary of these recent findings and implications for the relationship between familiarity-based recognition and recollection are discussed below.

Summary of ERP evidence supporting dual-process models

A number of recent studies (e.g., Curran, 2000; Duzel *et al.*, 1997; Rugg *et al.*, 1998; Tendolkar *et al.*, 1999) have provided evidence that familiarity and recollection are functionally dissociable components of recognition memory. The finding of an early frontal effect, predictive of recognition accuracy but insensitive to depth of processing manipulations (Rugg *et al.*, 1998), yet sensitive to an item's global-familiarity level as evidenced by its elicitation for both studied items and lures (Curran, 2000), and associated with preserved recognition memory in amnesic and Alzheimer's patients (Duzel *et al.*, 2001; Tendolkar *et al.*, 1999) is consistent with the notion of an acontextual and automatic process supporting familiarity-based recognition. In contrast, the left parietal old/new effect, sensitive to depth of processing manipulations and the intentional retrieval of source information (Curran, 2000; Rugg *et al.*, 1998), yet absent in amnesic and

Alzheimer's patients who have marked deficits in retrieving source memory (Duzel *et al.*, 1997; Tendolkar *et al.*, 1999), supports proposals that recognition further comprises an intentional recollective component which allows conscious access to contextual information.

These findings also have implications regarding the type of relationship that exists between the recognition components of familiarity and recollection. A relationship of redundancy would be proposed if familiarity could be found independently of recollection but recollection always co-occurred with familiarity. Alternatively, if familiarity and recollection were never found to co-occur, this would suggest a relationship of exclusivity between these processes. However, reports that the early frontal effect may occur independently of the parietal effect (e.g., Curran, 2000), the parietal effect may occur independently of the early frontal effect (e.g., Tsivilis, Otten & Rugg, 2001 - see below) and yet the two effects may also occur together (Rugg *et al.*, 1998), suggest that familiarity and recollection share a relationship of independence. However, strong conclusions cannot be drawn when considering the fact that ERPs are based on averaged, as opposed to single, trials. Accordingly, for each individual trial, we might find that familiarity and recollection never occur together which would support the notion of an exclusivity relationship. In any case, the above proposals are based on the assumption that the early frontal and parietal effects truly reflect processes underlying familiarity and recollection. Some very recent evidence, however, questions these assumptions and suggests that these ERP effects may, in fact, only reflect familiarity and recollection indirectly. The following sections will consider

further evidence relating to the functional significance of the early frontal and left parietal old/new effects in turn.

Functional significance of ERP correlates of recognition memory

Early frontal effect

The early, frontally-distributed ERP old/new effect has a latency range of around 300-500 msec post-stimulus and shows an attenuated negativity for old items in comparison to new items. This effect is insensitive to depth of processing manipulations (e.g., Rugg *et al.*, 1998), is predictive of recognition accuracy (Rugg *et al.*, 1998), is elicited by correctly identified old items as well as false alarms from lures (Curran, 2000) and onsets earlier than the left parietal old/new effect. Therefore, this evidence is consistent with the notion that the early frontal effect may be a neural correlate of familiarity-based recognition.

Mecklinger (2000) considered the possibility that the familiarity and recollection components of recognition memory may map on to content-specific memories. Having noted reports from a patient study (Pigott & Milner, 1993) that different processes may underlie recognition memory for object forms and spatial locations, Mecklinger (2000) used ERPs to investigate whether such processes may be orthogonal to or, alternatively, reflect the different contributions of familiarity and recollection to recognition memory. During study, participants were asked to memorise four object forms along with their spatial locations. At test, participants were cued as to whether a recognition judgement was required for object forms or for spatial locations. ERPs showed an early frontal effect only for correctly identified objects and a later parietal effect only for correct identification of spatial locations, suggesting a content-specific brain organisation for object-based and

spatially-based recognition memory. Furthermore, given their timing and scalp distribution, these effects seemed to reflect the processes underlying familiarity and recollection respectively. Mecklinger (2000) suggested that the early frontal effect may be elicited by items that can be represented as a unitised, or semantic, code that gives rise to increased processing fluency leading to the phenomenal experience of familiarity. Mecklinger (2000) based this proposal on suggestions that another closely related ERP component, the N400, is thought to reflect the integration of the item with its task context (e.g., Rugg & Doyle, 1994). Therefore, the early frontal effect may be sensitive to specific object-context associations formed during study (Weiskrantz, 1997). In contrast, spatial location may be encoded into a visual-structural, rather than conceptual, representation which, although it may be recollected, does not allow for contextual integration (Mecklinger, 2000).

However, some recent findings question the sensitivity of the early frontal effect to pre-formed object-context associations (Tsivilis *et al.*, 2001). Tsivilis *et al.'s* (2001) experiment required participants to study a series of pictures comprising object-context pairs and then to discriminate between old and new objects at test. Stimuli at test took one of five different forms: unmodified studied object-context pairs (SAME); recombined studied object-context pairs (REARRANGED); studied object-new context pairs (OLD/NEW); new object-studied context pairs (NEW/OLD); and new object-new context pairs (NEW/NEW). An early frontal old/new effect was elicited by correctly recognised SAME and REARRANGED pairs but was absent for correctly recognised OLD/NEW pairs, therefore, demonstrating context sensitivity. However, the

authors noted that, as the effect did not differ between SAME and REARRANGED pairs, the early frontal effect did not seem to be sensitive to specific object-context associations formed during study (Tsivilis *et al.*, 2001). Furthermore, the finding that OLD/NEW pairs did not elicit an early frontal effect (unlike REARRANGED pairs) did not seem consistent with the idea that this effect directly reflects familiarity. If it did, then recognition performance for OLD/NEW pairs would have had to rely almost exclusively on recollection. However, this seemed unlikely given that behavioural performance was equivalent for OLD/NEW and REARRANGED pairs, as were estimates of the relative contributions of recollection and familiarity to recognition performance (as measured by the remember/know procedure) (Tsivilis *et al.*, 2001). Therefore, it was suggested that the early frontal effect, rather than directly reflecting familiarity-based recognition, may reflect processes 'downstream' from those underlying familiarity and was, possibly, sensitive to novel aspects of the experimental context (Tsivilis *et al.*, 2001).

Other studies also indicate inconsistencies regarding the elicitation of the early frontal effect. For example, while findings from some investigations suggest that the early frontal effect reflects an amodal familiarity process (e.g., Curran & Dien, 2003), more recent findings indicate that this effect is, in fact, sensitive to format change between an item's initial and subsequent encounter (Schloerscheidt & Rugg, 2004). Furthermore, the absence of early frontal effects have also been reported for repeated, pre-experimentally non-familiar faces (Yovel & Paller, 2004). This evidence suggests that familiarity may not, in fact, be indexed generically by the early frontal old/new effect. Interestingly, Xiang and Brown

(1998) have shown that, in non-human primates, neurons respond to repeated complex visual stimuli within 100 msec of their presentation. Furthermore, this effect has been proposed to reflect familiarity-based recognition (Brown & Bashir, 2002; Brown & Xiang, 1998) – if this interpretation is correct, it would seem that the early frontal old/new effect may occur too late to directly reflect familiarity processing. Consistent with this idea, in Tsivilis *et al.'s* (2001) study described above, a very early (100-300 msec post-stimulus) old/new effect found over frontopolar sites was reported as being sensitive to the repetition of all object/context pairs containing at least one studied component. These findings suggested that, while the early frontal effect may reflect processes 'downstream' from those underlying familiarity, these very early effects might, perhaps, reflect familiarity processing more directly.

Left parietal effect

The left parietal old/new ERP effect consists of a positive-going waveform for correctly identified old items in comparison to new items, which is maximal over left parietal sites and onsets at around 500 msec post-stimulus. This effect is enhanced when an item's source is correctly, rather than incorrectly, identified (e.g., Wilding, 2000; Wilding & Rugg, 1996), is larger for 'remember' judgements in comparison to 'know' judgements (e.g., Duzel, Yonelinas, Mangun, Heinze & Tulving, 1997; Smith, 1993; Trott, Friedman, Ritter, Fabiani & Snodgrass, 1999) and is sensitive to depth of processing manipulations (e.g., Paller, Kutas & McIsaac, 1995; Rugg, Allan & Birch, 2000; Rugg *et al.*, 1998). This effect has not been reported for old items incorrectly identified as new or for new items incorrectly identified as old (apart from when false alarms have been due to 'false

recollection') which suggests that this effect is elicited by veridical recognition judgements. In sum, the above findings indicate that the left parietal old/new ERP effect may be a neural correlate of recollection.

Although findings from a number of ERP studies investigating dual-process models support the above conclusion, more recent findings from studies employing the exclusion task suggest that the functional significance of the left parietal effect may be more complex than originally thought (Dywan, Segalowitz & Webster, 1998). The exclusion task, modified from the Process Dissociation Procedure (e.g., Jacoby, 1991; Jacoby, Toth & Yonelinas, 1993), requires an 'old' response to only one class of studied items from a specified study source ('targets') and the rejection of all other items, including studied items from an alternative study source ('non-targets') as well as unstudied ('new') items. It is assumed that differential responding to the two classes of studied items in the exclusion task may only be achieved through intentional and controlled recollective processing – although correct responding to targets could be based on familiarity and/or recollection, correct rejection of non-targets requires the retrieval of their study source (Jacoby, 1991). However, some ERP studies employing the exclusion task (Dywan, Segalowitz & Arsenault, 2002; Dywan *et al.*, 1998; Dywan, Segalowitz, Webster, Hendry & Harding, 2001; Herron & Rugg, 2003a; 2003b) have shown that correctly rejected non-targets may sometimes fail to elicit a left parietal old/new effect. Considering this effect is held to reflect processes of recollection, it seems that the retrieval of source information may not always be necessary to reject non-targets. In Dywan *et al.*'s (1998) study, younger and older participants were required to endorse studied items (targets) and reject both new items and repeated

foils (non-targets). Although older participants were relatively poor at rejecting non-targets, they nevertheless showed left parietal old/new effects for both non-target and target items. In contrast, while younger participants were more accurate in terms of rejecting non-targets, for this group, left parietal old/new effects were elicited by targets only. Dywan *et al.* (1998) suggested that the left parietal old/new effect may be sensitive to the *task relevance* of retrieved information, and that the absence of this effect for non-targets in younger participants reflects their greater ability to inhibit retrieval of [irrelevant] non-target source (see also Dywan *et al.*, 2002; 2001).

Herron and Rugg (2003a) reported a similar pattern of findings across two experiments involving a depth of processing manipulation. For both experiments, participants were required to engage in a deep encoding task for items designated as non-targets (i.e., items from study list 1). For items designated as targets (i.e., items from study list 2), the encoding task was also deep in Experiment 1, but shallow in Experiment 2 – these tasks were chosen to elicit good memory for targets in the first experiment, but poor memory for targets in the second experiment. At test, left parietal old/new effects were elicited for correctly identified targets in both experiments, but the effect was elicited for correctly rejected non-targets only in Experiment 2. With good target memory (Experiment 1), it seemed that these items could be identified on the basis of retrieved information diagnostic of their study source, and non-targets could be rejected on the basis of the absence of this information. However, when the availability of target source information was reduced (Experiment 2), the absence of this information could no longer provide a reliable basis to reject non-targets. In this

case, it was necessary to recollect non-target source. These findings suggest that a retrieval strategy may be adopted that allows processing resources to be devoted to the retrieval of target source at the expense of non-target recollection. The authors initially proposed that non-target source information was, in fact, retrieved in both experiments but was only attended to in experiment 2 (Herron & Rugg, 2003a). This proposal is consistent with other findings that suggest the left parietal old/new effect may be sensitive to the task-relevance of retrieved information (Duzel *et al.*, 1999; Paller, Kutas & McIsaac, 1995; Rugg & Wilding, 2000) and may be understood when recollection is defined as the retrieval of episodic information in service of the conscious control of behaviour (e.g., Jacoby & Kelley, 1992). Given this view, as participants did not make use of recollected non-target information in experiment 1, the absence of a left parietal old/new effect for these items reflects the fact that they were not excluded on the basis of recollection of their study source. Herron & Rugg (2003b) alternatively proposed that the adoption of a specific 'retrieval orientation' might underlie the above strategy, enabling test cues to be processed in a way that selectively probes for target recollection. This idea will be further explored later in this thesis.

Summary

ERP studies have provided strong evidence for a number of dissociable processes supporting recognition memory: the early frontal old/new effect thought to reflect familiarity-based recognition; the left parietal old/new effect proposed as a neural correlate of recollection; and a right frontal ERP effect thought to reflect the monitoring of retrieved information or the evaluation of the products of a retrieval attempt. Given that the functional significance of these ERP old/new

effects have been basically agreed upon, they can be utilised as tools to monitor the involvement of specific cognitive processes in recognition memory tasks. In support of dual-process models, the finding that the early frontal and left parietal ERP effects differ qualitatively suggests that familiarity and recollection are functionally dissociable components of recognition memory. However, evidence from more recent studies question the functional significance of the early frontal and left parietal effects and indicate that they may not reflect, respectively, familiarity and recollection directly. With regard to the functional significance of the left parietal effect, interpretations of the data will rely on the particular mechanism(s) thought to underlie the selective retrieval of some types of information at the expense of others. This question, in particular, will be addressed in the series of experiments to be presented in this thesis.

CHAPTER 4

General Methods

Methods common to all four experiments are described in this chapter. Details of procedures relating more specifically to individual experiments can be found in the method sections of the relevant chapters. All experiments were approved by the joint ethics committees of the University College London and the University College London Hospitals.

Experimental paradigm

An 'exclusion' task, derived from the Process Dissociation Procedure (e.g., Jacoby, 1991; Jacoby, & Kelley, 1992), was employed in all four experiments. Each experimental session comprised two experimental blocks (Experiments 1-3), or one experimental block for each of two groups (Experiment 4), each of which represented a single experimental condition and consisted of three phases; study list 1, study list 2 and test. For the test phase, the exclusion task required the endorsement of 'targets' from study list 2 and the rejection of all other items, including 'non-targets' from study list 1 and 'new' items. The exclusion task was originally developed in conjunction with the 'inclusion' task (requiring the endorsement of all studied items) in order to separate and estimate the contributions of familiarity and recollection to recognition memory performance. For the experiments reported in this thesis, however, only the exclusion task was employed. Experimental manipulations of encoding operations were employed to further elucidate the functional significance of ERP correlates of recognition memory.

Participants

Participants were drawn from a population of undergraduate and graduate student volunteers from UCL. All participants were right-handed and spoke English as their first language. They were aged between 18 and 35 years, and had normal or corrected-to-normal vision. Participants gave informed consent before taking part in the experiment and were reimbursed at the rate of £7.50 per hour (plus travel expenses).

Stimuli

Critical stimuli consisted of 360 concrete nouns which were taken from the low-to-medium frequency range of the Kucera and Francis corpus (Kucera & Francis, 1967) and varied in length from 3-9 letters. From a subset of 240 of these critical items, 4 study lists of 60 items were created. From the remaining pool of 120 items, another 2 lists of 60 words were created to be used as new words at test. There were 8 additional filler items. Both non-target study lists (i.e., study list 1) and target study lists (i.e., study list 2) comprised 60 items with 2 filler items added to the beginning of each list. Each of the 4 study lists was rotated such that, across participants and for both conditions, each study list served equally often as non-target and target items. Each test list contained 180 critical words, comprising 60 words corresponding to the non-target study list, 60 words corresponding to the target study list and a further 60 new words. Presentation of each of the two lists comprising the new words at test was fully counterbalanced across study list orderings and condition. Critical test words were randomly ordered for each participant. Two filler words were added to the beginning of each test list and another 2 filler words were added after the 90th critical test word. For the within-

subject designs (Experiments 1-3), the order in which participants completed each condition was fully counterbalanced across study-test list orderings.

Procedures

After being fitted with an electrode cap (see below), participants were seated in a sound-attenuated recording booth facing a display monitor which presented the experimental stimuli in central vision. Participants were then informed that they would be taking part in a memory experiment consisting of a study phase and a test. However, participants were asked to avoid using any strategies during study that might enhance their performance at test and to simply focus on the task requirements during the study phase. For the within-subject designs (Experiments 1-3), each participant completed two study-study-test blocks, each block corresponding to a different experimental condition. For the between-subject design (Experiment 4), half of the participants completed a single block corresponding to one condition while the other half completed a single block corresponding to the alternative condition. In the following order, each block consisted of a non-target study phase, a target study phase and a test phase. An interval of two minutes separated each phase in each block. During this interval, participants were required to count backwards aloud in threes from a number arbitrarily specified by the experimenter for a duration of one minute and then to engage in conversation with the experimenter. When required to complete two blocks, participants were given a five minute rest period between completion of the first block and commencement of the second block.

For each experimental block, study and test phases were initiated by the experimenter pressing the space-bar on the computer keyboard. The instruction,

'GET READY', was presented before alerting participants as to which list they were about to study ('List 1' for the non-target study list and 'List 2' for the target study list) and before the appearance of the first word in the test list. Study and test trials consisted of the presentation of a fixation character ('!') for 1000 msec, after which the screen was blanked for 120 msec followed by the presentation of the stimulus for 600 msec. The screen was then blanked for 100 msec followed by another fixation character ('+') which, for the study phase, stayed on screen until the experimenter initiated the next trial. For test trials, the latter fixation character stayed on screen for 2000 msec and then the screen was blanked for 100 msec before moving on to the next trial. During test, brief rest intervals were provided after the 92nd trial.

For non-target and target study phases, different orienting tasks were chosen according to the particular condition and /or experiment. For all study phases, each trial was initiated by the experimenter after receiving a verbal response relating to the previous trial as required by the task. Instructions for the test phase were identical for all conditions and experiments. For the purposes of EEG recording, participants were required to relax, to fixate their gaze at the centre of the screen where stimuli were to be presented and to avoid all eye movement other than blinking. Participants rested their index finger from one hand on one response key and their index finger from the other hand on another response key. For each trial, participants were required to press one key only if the stimulus word had been presented during the target study phase and the other key for all other stimulus words. Therefore, the latter category of words included 'new' words (i.e., words that did not correspond to items presented during either study phase) as well

as words corresponding to items presented during the non-target study phase. The mapping of hand to response type was fully counterbalanced across participants as well as across ordering of study-test lists and conditions. Participants were asked to respond as quickly as possible but not to trade off accuracy for speed – any responses faster than 300 msec or slower than 2500 msec were rejected as errors. All participants received a short study-test practice block prior to commencing each experimental block.

EEG recording

EEG was recorded from 31 silver/silver chloride electrodes. Twenty-nine of these electrodes were embedded in an elasticated cap, a subset of the 'montage 10' provided by the supplier of the electrode cap (Falk Minow Services "easycap": http://www.easycap.de/easycap/english/schemae.htm - see figure 4.1).

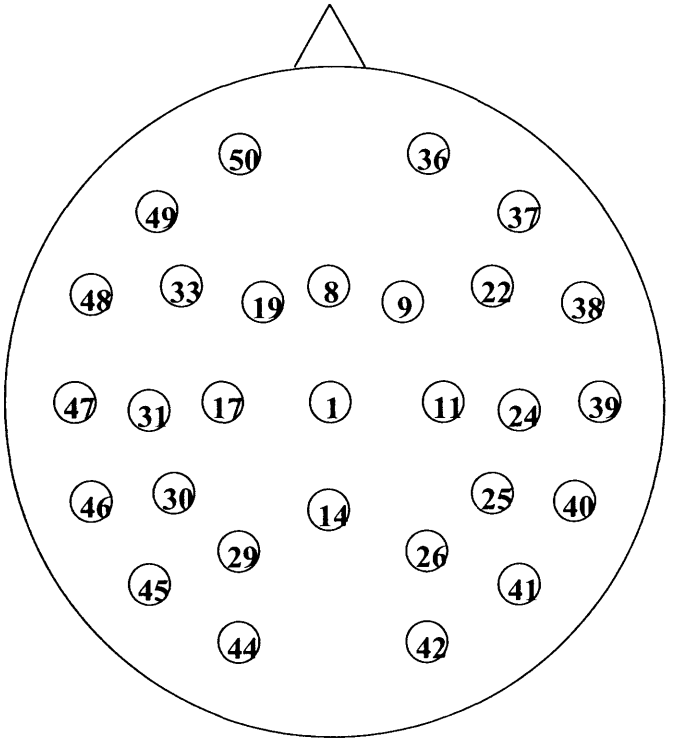

Figure 4.1: The 29 selected electrode sites from the 'montage 10' equidistant recording system.

The remaining 2 electrodes were placed on the left and right mastoid processes. Horizontal EOG was recorded from electrodes placed on the outer canthus of each eye and vertical EOG was recorded from electrodes placed above and below the right eye. Recordings were made with reference to the mid-frontal electrode (site '8' from the montage 10 system – typically known as 'Fz') and, subsequently, re-referenced off-line to linked mastoids. EEG and EOG were amplified with a bandwidth of 0.03-35 Hz (3dB points) and digitised (12-bit resolution) at a sampling rate of 8 msec per point (125 Hz). Prior to averaging, the EEG was digitally smoothed with an upper cut off frequency (3dB) of 19.4 Hz, and trials containing horizontal or vertical eye movements other than blinks were rejected, as were trials for which A/D saturation occurred or baseline drift exceeded ±50.0 microvolts. To minimise the number of trials rejected due to blink artefact, a correction procedure was applied which estimated and corrected the contribution of the vertical EOG to the scalp EEG with the use of a linear regression technique.

For each test trial, the recording epoch lasted for a duration of 2048 msec, which included a 104 msec pre-stimulus baseline period to give a post-stimulus recording epoch of 1944 msec. Averaged ERPs were formed for the 3 item types of interest: correctly classified targets; correctly rejected non-targets; correctly rejected new items. In order to achieve an adequate signal-to-noise ratio in the ERP data, participants were excluded if they contributed less than 16 artefact-free trials forming ERPs to any critical item type.

Data analyses

Behavioural and ERP data were analysed using repeated measures ANOVA for Experiments 1-3 and a mixed-design ANOVA with one between-subjects factor

for Experiment 4. Where necessary, F-ratios are reported with degrees of freedom corrected for non-sphericity (Greenhouse & Geisser, 1959). For the behavioural analyses, ANOVAs were performed on accuracy and reaction time (RT) data and any contrasts of interest were carried out with Bonferroni t-tests. For the ERP data, all statistical tests used an alpha level of .05. In all cases, effects that did not involve factors of item type or condition / group are not described. Both magnitude and topographic analyses were conducted as detailed below.

Magnitude analyses

The data associated with the 3 item types of interest in each condition were quantified by measuring the mean amplitude (relative to the pre-stimulus baseline) over six latency regions: 100-300 msec, 300-500 msec, 500-800 msec, 900-1100 msec, 1100-1400 msec and 1400-1900 msec. These regions were selected to correspond with those typically employed in previous comparable studies (e.g., Schloerscheidt & Rugg, 2004; Wilding, 1999) while also taking into account visual inspection of the waveforms in the present experiments. Analyses within each latency region took the form of initial global ANOVAs conducted on data from a distributed grid of 18 electrode sites in order to identify which scalp locations were sensitive to the experimental manipulations. This grid was factored according to hemisphere, anterior-posterior chain (frontal, temporal, parietal) and site (inferior, mid-lateral, superior) and included lateral frontal sites (48, 33, 19, 38, 22, 9), lateral temporal sites (47, 31, 17, 29, 24, 11) and lateral parietal sites (46, 30, 29, 40, 25, 26). First, data from each condition were analysed separately in order to establish reliable differences in the ERPs between the three item types. When the overall ANOVA gave rise to significant effects of item, subsidiary ANOVAs were

conducted to separately contrast ERPs to targets, non-targets and new items with each other. A second set of global ANOVAs were conducted within each latency region in order to directly contrast reliable target and non-target old/new effects according to condition. These analyses were conducted on difference scores (old-new) rather than raw amplitude data.

An additional set of focused analyses on specific sites of interest were guided *a priori* by the ERP literature. These were conducted so that any effects associated with established ERP correlates of recognition memory as a function of item type and/or condition / group could be detected with maximum sensitivity. Previous research has revealed at least three ERP old/new effects thought to index processes of explicit recognition that can be identified on the basis of their time course, scalp distribution and sensitivity to various experimental manipulations (see chapter 3, 'ERP studies of recognition memory', for a review). In the present experiments, the early mid-frontal positivity, thought to index processes of familiarity-based recognition, was investigated using data from mid-frontal sites (19, 8, 9) during the 300-500 msec latency region. Data from lateral parietal sites (46, 30, 29, 40, 25, 26) during the 500-800 msec latency region was analysed to investigate the 'left parietal old/new effect', thought to reflect processes of recollection. Finally, the later-onsetting 'right frontal' old/new effect, held to reflect monitoring and evaluative operations, was investigated with data from lateral frontopolar sites (49, 50, 37, 36) during the 1100-1400 msec and 1400-1900 msec latency regions. These latter sites were chosen as this effect has previously been observed over prefrontal sites (e.g., Senkfor & Van Petten, 1998) and was

sometimes apparent over these sites in the grand average waveforms of the experiments to be reported in this thesis.

Topographic analyses

Differences in the scalp topography of reliable target and non-target old/new effects were investigated, when appropriate, both within and across condition / group, as well as across different latency regions (as described above). The use of topographic analyses provides a means of assessing whether ERP effects differ qualitatively (i.e., due to the activation of different neural generators) across different experimental conditions and/or latency regions. These analyses were conducted on difference scores (old-new) derived from all 29 electrodes and reveal reliable differences when significant condition / group x site interactions are obtained. There are potential problems, however, when using an ANOVA model as changes in the activity of neural generators have multiplicative, rather than additive, effects on the amplitude measures detected at the scalp. Therefore, when an experimental manipulation elicits a simple change in dipole strength, differential changes in amplitude will be detected at different electrode sites, resulting in a misleading condition / group or latency region x site interaction. In order to satisfy the additivity assumption of the ANOVA, the ERP data was rescaled prior to analysis (McCarthy & Wood, 1985). This method calculates the amplitude of the ERP effect of interest at each electrode site relative to all other sites and maintains a pattern of relative differences in the size of the effect across the scalp while removing differences in amplitude. Finally, the scalp distribution of ERP effects were displayed using spline maps showing the relative size of the effect (in microvolts) across the surface of the scalp. This technique was used to highlight

any significant differences in the scalp distribution of ERP effects between experimental conditions.

CHAPTER 5

The employment of different retrieval strategies in an exclusion task and their influence on ERP correlates of recollection: Experiments 1 and 2

Introduction

Experiments 1 and 2 investigated how the use of retrieval strategies in an exclusion task might modulate ERP correlates of recollection. Recent ERP studies employing the exclusion task (Dywan *et al.*, 2002; 1998; 2001; Herron & Rugg, 2003a) have shown that, under certain circumstances, correctly rejected non-targets may fail to elicit a left parietal old/new ERP effect (for a review, see chapter 3). Considering this effect is held to reflect processes of recollection, these findings are in direct opposition to the assumptions underlying the PDP – that non-targets may only be rejected through the recollection of their study source (Jacoby, 1991). Herron and Rugg (2003a) suggested, however, that it may not always be necessary to recollect non-target study source. If, for example, test items corresponding to targets were endorsed only when accompanied by the relevant source-identifying information, a decision to reject non-targets could be based on the absence of such information. In their study, Herron and Rugg (2003a) used a depth of processing manipulation across two experiments in order to elicit differing levels of recognition accuracy for targets. Although non-target accuracy was equivalent in the two experiments, they found that correctly rejected non-targets elicited a left parietal old/new effect only when memory for targets was poor. In this case, given a reduction in the availability of target source information, the absence of this

information could not provide a reliable basis to reject non-targets. Therefore, it was necessary to recollect non-target source. However, when memory for targets was good, targets could be endorsed on the basis of retrieved information that identified their study source, and non-targets were rejected on the basis of the absence of this information. In this case, it was not necessary to retrieve non-target source information.

These findings suggest that a retrieval strategy can be adopted that allows processing resources to be dedicated to the exclusive retrieval of target source information. In terms of possible mechanisms underlying such a strategy, Herron and Rugg (2003a) initially proposed that an 'attentional bias' (cf. Anderson & Bjork, 1994) might account for their findings. According to this explanation, non-target source information was retrieved in both experiments but was only *attended* to when memory for targets was poor. If this explanation is correct, it would seem that the left parietal old/new effect may be sensitive to the *task relevance* of retrieved information (Duzel *et al.*, 1999; Paller *et al.*, 1995; Rugg & Wilding, 2000). However, in light of their findings from another ERP study employing the exclusion task, Herron and Rugg (2003b) proposed that the above strategy reflects the adoption of a 'retrieval orientation', enabling test cues to be processed in a way that selectively probes for target recollection. The idea that specific retrieval orientations can be maintained during recognition is supported by investigations that have contrasted neural activity associated with the presentation of test cues across tasks that vary the nature of the memory representation being sought (for reviews, see Donaldson, Wilding & Allan, 2003; Wilding & Sharpe, 2003). These contrasts have been limited to 'new' test items so as to eliminate possible

confounds with retrieval success (Rugg & Wilding, 2000). For example, Robb and Rugg (2002) contrasted ERPs elicited by (new) test words during a yes/no recognition task across two conditions, one of which employed pictures as the study material, while the other used words. It was argued that different retrieval orientations would be adopted according to whether picture or word representations were being sought, and that these orientations would be reflected in differences between ERPs to new test words associated with the two conditions. As expected, from approximately 250 msec, this contrast evidenced large differences between the ERP waveforms, with ERPs to new test items showing a topographically widespread and sustained positivity when words, relative to pictures, were being sought.

These findings were replicated by Herron and Rugg (2003b) in an exclusion task using words and pictures intermixed at study. Pictures were designated as targets in one condition, and words were designated as targets in the other – words were used as retrieval cues in both conditions. Given that new items elicited more positive ERPs when words rather than pictures were to be retrieved as targets, these findings seemed to reflect the adoption of different retrieval orientations according to type of target material. Importantly, however, the 'old/new' effects reported in this study suggest that a specific retrieval orientation was adopted in one condition only – when words were used to search for target words, correctly rejected non-target pictures failed to elicit a left parietal old/new effect. In contrast, when words were used as cues to search for target pictures, correctly rejected non-target words gave rise to a left parietal old/new effect. Therefore, while a test word could be used to selectively retrieve episodic information involving target words as opposed

to non-target pictures, such specificity could not be obtained when the same cue was used to retrieve episodic information involving target pictures (Herron & Rugg, 2003b).

The aim of the present study was to explore the parameters affecting the strategic use of retrieval orientation to reject non-target information. Experiment 1 investigated whether the ERP correlates of recollection would differ according to the retrieval strategies employed in two versions of an exclusion task. In the 'picture condition', non-targets were pictures and, in the 'word condition', non-targets were words – in both conditions, targets and test cues were words. Study tasks were chosen to elicit good memory for non-targets and poor memory for targets. For the word condition, given that the availability of target source information should be minimal, it was proposed that the absence of this information could not provide a reliable basis to reject non-targets. In this case, it was expected that non-targets would require the recollection of their study source in order to successfully reject these items. Therefore, for the word condition, it was predicted that correctly rejected non-targets would elicit a left parietal old/new ERP effect. However, if test words can be employed to selectively retrieve episodic information relating to target words as opposed to non-target pictures, test words corresponding to non-targets in the picture condition should not give rise to the retrieval of their study source. Therefore, it was predicted that correctly rejected non-targets in the picture condition should fail to elicit a left parietal old/new ERP effect.

Experiment 1

Method

Participants

Twenty one undergraduate and graduate students participated in this experiment. Data from 5 of the participants were discarded due to insufficient (i.e., less than 16) artefact-free trials in one or more of the critical conditions. Of the remaining 16 participants, 8 were male and 8 were female, and their ages ranged between 20-29 years (mean age: 23 years).

Stimulus materials

Critical stimuli consisted of 360 words (concrete nouns) and 240 colour pictures of objects, each picture corresponding to one member of a subset of the words – picture-word correspondence was operationalised as picture name agreement between at least 5 out of 6 participants from a previous pilot study (Herron & Rugg, 2003b). From the pool of 240 pictures, 4 study lists of 60 pictures were created, and each picture list was paired with a word list containing corresponding words. From the remaining pool of words, another 2 lists of 60 words were created to be used as new words at test. There were 8 additional filler pictures and corresponding words. Non-target study lists (i.e., study list 1) comprised 60 pictures for the picture condition and 60 words for the word condition with 2 filler pictures/words added to the beginning of each list. Target study lists (i.e., study list 2) contained 60 words for both the picture and word conditions, again, with 2 filler words added to the beginning of the list. The 4 study lists were rotated such that each study list served equally often as non-target and target items in both the picture and word conditions. Each test list contained 180

critical words comprising 60 words corresponding to the non-target study list, 60 words from the target study list and a further 60 new words. Presentation of each of the two lists comprising the new words at test was fully counterbalanced across study list orderings and condition. Critical test words were randomly ordered for each participant. Two filler words were added to the beginning of each test list and another 2 filler words were added after the 90th critical test word. The order in which participants completed each condition was fully counterbalanced across study-test list orderings.

Experimental design

The experiment employed a 2 (condition: picture; word) x 3 (item: targets; non-targets; new items) within-subject design, and consisted of 2 blocks, each comprising three phases; study list 1, study list 2 and test. Figure 5.1 provides an overview of the design, including examples of the different types of study and test items, along with their correct responses at test.

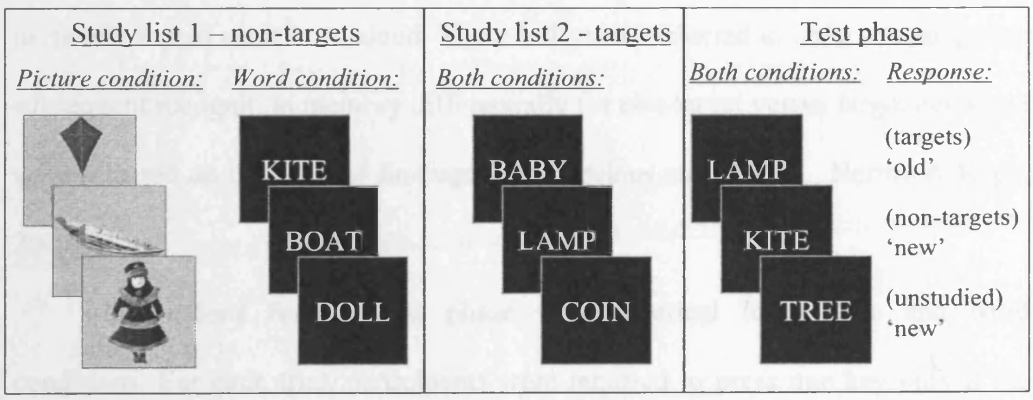

Figure 5.1.
Experimental design. Study-study-test blocks in each condition, with examples of study/test items and their correct responses at test.

Procedure

See chapter 4 for details of the procedure common to all experiments. Each participant completed two study-study-test blocks, one block corresponding to the picture condition and the other corresponding to the word condition. All stimuli were presented in central vision – words and pictures were presented within a white frame subtending a vertical and horizontal visual angle of 3.7 degrees. Words subtended a vertical visual angle of 0.4 degrees and a maximum horizontal angle of 2.0 degrees. Pictures were presented against a grey background and words were presented in white upper case letters against a black background.

For the non-target study phase, participants were required to perform one of two tasks depending on whether pictures or words were presented. If the non-target study list contained pictures, participants were required to verbally respond 'yes' to each stimulus if the pictured object could fit inside a shoebox and 'no' if it could not. If the non-target study list contained words, participants were required to incorporate each word into a self-constructed sentence and to verbally repeat this sentence aloud. For target study lists in each condition, participants were required to merely repeat each word aloud. These tasks were selected in order to manipulate subsequent recognition memory differentially for non-target versus target items and were selected on the basis of findings from previous studies (e.g., Herron & Rugg, 2003a).

Instructions for the test phase were identical for picture and word conditions. For each trial, participants were required to press one key only if the stimulus word had been presented during the target study phase and the other key for all other stimulus words. Therefore, the latter category of words included 'new'

words (i.e., words that did not correspond to items presented during either study phase) as well as words corresponding to items presented during the non-target study phase (either as a picture or as a word depending upon the condition). The mapping of hand to response type was fully counterbalanced across participants as well as across ordering of study-test lists and conditions.

Results

Behavioural data

Accuracy and reaction time data are summarised in Table 5.1. For the accuracy data, ANOVA revealed a main effect of item [$F(1.2,18.1) = 36.36$, $p < 0.001$]. Pairwise contrasts revealed that responses to new items were more accurate than responses to both targets [$F(1,31) = 62.17$, $p < 0.001$] and non-targets [$F(1,31) = 8.38$, $p < 0.01$]. There were fewer accurate responses to targets than to non-targets [$F(1,31) = 47.61$ $p < 0.001$]. ANOVA of the RT data gave rise to a main effect of condition [$F(1,15) = 10.43$, $p < 0.01$], a main effect of item [$F(2,30) =$

Table 5.1.
Exp. 1 – Mean percent accuracy and reaction time (including standard deviations) for correctly classified targets, non-targets and new items as a function of condition.

CONDITION	ITEM TYPE	% CORRECT	RT (SD)
Picture	Targets	60 (15)	1100 (249)
	Non-targets	86 (8)	1113 (272)
	New	90 (7)	1084 (308)
Word	Targets	60 (17)	1241 (291)
	Non-targets	82 (11)	1221 (253)
	New	87 (11)	1086 (253)

5.80, $p < 0.01$] and a condition x item interaction [$F(2,30) = 6.18$, $p < 0.01$]. Pairwise tests revealed significantly faster RTs for targets [$F(1,15) = 10.28$, $p < 0.01$] and non-targets [$F(1,15) = 11.95$, $p < 0.005$] from the picture condition in comparison to those from the word condition, but no significant difference in RTs between new items as a function of condition. One-way within-subjects ANOVAs found a main effect of item for the word condition [$F(1.4,20.7) = 9.67$, $p < 0.005$] but not for the picture condition [$F < 1$]. For the word condition, Bonferroni t-tests (adjusted alpha level: 0.017) revealed significantly longer RTs for targets ($t(15) = 3.80$, $p < 0.005$) and non-target items ($t(15) = 5.85$, $p < 0.001$) compared to new items but no significant difference between target and non-target items.

ERP data

Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at selected electrode sites are shown in figure 5.2 for the picture condition and in figure 5.3 for the word condition. The mean number (and range) of trials contributing to averaged ERPs for target, non-target and new items were 31 (19-51), 44 (25-56) and 45 (24-53) respectively for the picture condition and 29 (16-50), 40 (21-55) and 42 (22-54) respectively for the word condition.

For both conditions, target ERPs diverge from both non-target and new item ERPs at approximately 100 msec post-stimulus, with ERPs to targets being relatively more positive-going. This very early effect seems to be left-lateralised and maximal at superior temporal and mid-lateral sites for the picture condition but bilateral and maximal at superior frontal sites for the word condition. At

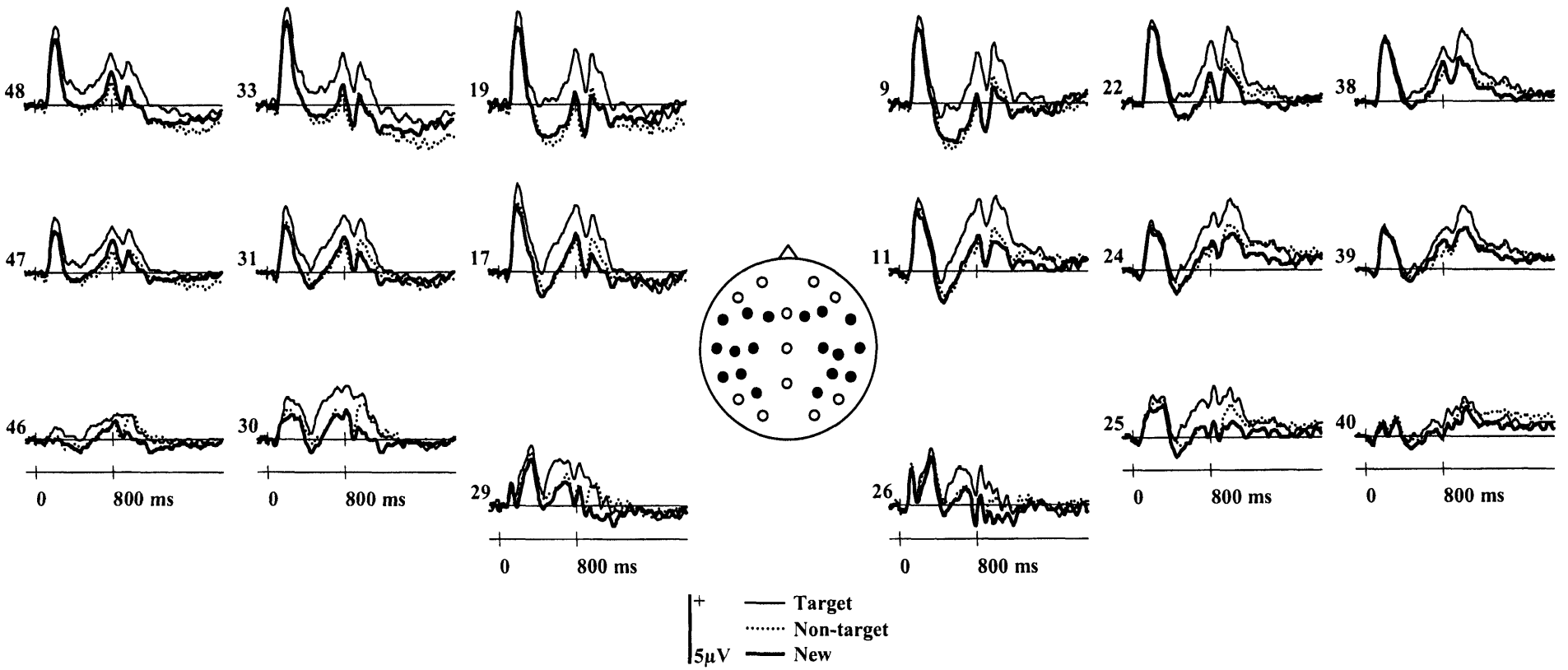

Figure 5.2.
Exp. 1 – Picture condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontal (48, 33, 19, 38, 22, 9), lateral temporal (47, 31, 17, 29, 24, 11) and lateral parietal sites (46, 30, 29, 40, 25, 26).

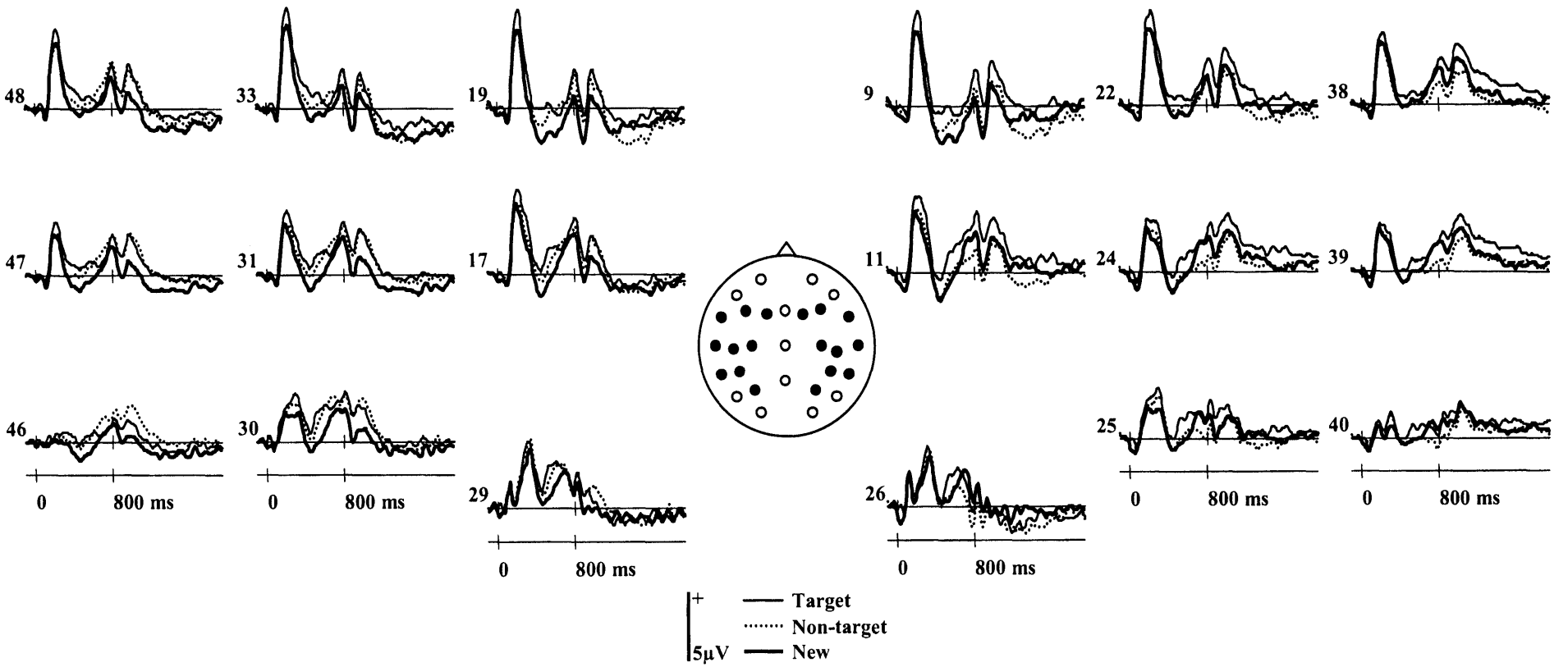

Figure 5.3.
Exp. 1 – Word condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at electrode sites as described in Figure 5.2.

superior frontal sites, from around 300 msec post-stimulus, ERPs to non-targets show a marked negativity which is undifferentiated from ERPs to new items for the picture condition and only slightly attenuated for non-target ERPs from the word condition. In contrast, this negativity is greatly attenuated for target ERPs from both conditions. From around 500 msec post-stimulus, target ERPs from both conditions show an enhanced positivity compared to new item ERPs, an effect that is widely distributed across the scalp and sustained for approximately 900-1200 msec post-stimulus. This positivity seems to be larger for target ERPs from the picture condition compared to those from the word condition. For non-target ERPs from the word condition, there is an enhanced positivity from around 500 msec post-stimulus, which is apparent over left inferior / parietal sites. This left parietal old/new effect is not apparent for non-targets in the picture condition until approximately 900 msec post-stimulus.

Data associated with targets, non-targets and new items from both conditions were quantified by measuring the mean amplitude (relative to the pre-stimulus baseline) over six latency regions: 100-300 msec, 300-500 msec, 500-800 msec, 900-1100 msec, 1100-1400 msec and 1400-1900 msec. For each of these latency regions, global ANOVAs were conducted on data from a set of 18 electrode sites, as described in Chapter 4. First, these analyses were conducted on data associated with targets, non-targets and new items for each condition separately, employing the factors of item, hemisphere, location (frontal, temporal, parietal) and site (inferior, mid-lateral, superior). The results of these ANOVAs are summarised in tables 5.2 and 5.3 for the picture condition and word condition respectively. However, as initial analysis of the 1400-1900 msec latency region

Table 5.2.
Exp. 1 – Summary of ANOVA results in each ERP latency region for the picture condition.

	100-300 msec	300-500 msec	500-800 msec	900-1100 msec	1100-1400 msec
Targets/non-targets/new					
IT	–	$F_{2,30} = 10.45$, $p < 0.001$	$F_{1.6,24.6} = 12.17$, $p < 0.001$	$F_{1.8,27.0} = 7.20$, $p < 0.005$	–
IT x HM	$F_{1.9,28.6} = 3.73$, $p < 0.05$	–	–	–	–
IT x AP	–	$F_{1.6,23.6} = 4.15$, $p < 0.05$	–	$F_{1.8,27.3} = 6.24$, $p < 0.01$	$F_{1.5,23.0} = 4.52$, $p < 0.05$
IT x ST	–	$F_{2.1,31.1} = 3.31$, $p < 0.05$	$F_{1.8,26.8} = 8.03$, $p < 0.005$	–	–
IT x HM x ST	–	$F_{2.5,38.0} = 2.98$, $p = 0.05$	–	–	–
Targets/new					
IT	$F_{1,15} = 10.59$, $p = 0.005$	$F_{1,15} = 24.41$, $p < 0.001$	$F_{1,15} = 14.59$, $p < 0.005$	$F_{1,15} = 11.21$, $p < 0.005$	–
IT x ST	–	$F_{1.1,16.3} = 5.35$, $p < 0.05$	$F_{1.0,15.6} = 9.37$, $p < 0.01$	$F_{1.1,16.4} = 4.25$, $p = 0.05$	–
Non-targets/new					
IT x AP	–	$F_{1.3,19.6} = 4.64$, $p < 0.05$	–	$F_{1.2,18.1} = 4.65$, $p < 0.05$	–
IT x HM x AP	–	–	–	$F_{1.3,19.4} = 4.17$, $p < 0.05$	$F_{1.4,21.0} = 6.93$, $p < 0.01$
Targets/non-targets					
IT	–	$F_{1,15} = 8.37$, $p = 0.01$	$F_{1,15} = 15.03$, $p = 0.001$	$F_{1,15} = 5.96$, $p < 0.05$	–
IT x HM	$F_{1,15} = 7.97$, $p = 0.01$	$F_{1,15} = 4.81$, $p < 0.05$	–	–	–
IT x AP	–	$F_{1.1,16.6} = 5.06$, $p < 0.05$	–	$F_{1.1,17.2} = 8.45$, $p < 0.01$	$F_{1.1,16.8} = 5.49$, $p < 0.05$
IT x ST	–	–	$F_{1.1,15.8} = 12.97$, $p < 0.005$	–	–
IT x HM x ST	$F_{1.2,18.4} = 5.57$, $p < 0.05$	$F_{1.5,22.1} = 8.00$, $p = 0.005$	–	–	–

IT = item type; HM = hemisphere; AP = location; ST = site.

Table 5.3.
Exp. 1 – Summary of ANOVA results in each ERP latency region for the word condition.

	100-300 msec	300-500 msec	500-800 msec	900-1100 msec	1100-1400 msec
Targets/non-targets/new					
IT	$F_{2.0,29.8} = 4.86$, $p < 0.05$	$F_{1.9,28.5} = 7.25$, $p < 0.005$	–	–	–
IT x HM	–	–	$F_{1.8,27.5} = 8.72$, $p < 0.005$	$F_{1.9,28.1} = 10.01$, $p = 0.001$	$F_{1.8,26.4} = 4.38$, $p < 0.05$
IT x AP	$F_{2.4,35.5} = 6.50$, $p < 0.005$	–	–	–	–
IT x HM x ST	–	–	–	$F_{2.4,36.6} = 3.57$, $p < 0.05$	–
IT x AP x ST	–	$F_{3.1,46.9} = 3.86$, $p = 0.01$	$F_{2.5,37.9} = 3.13$, $p < 0.05$	$F_{3.8,57.7} = 3.00$, $p < 0.05$	–
IT x HM x AP x ST	–	–	$F_{4.9,73.2} = 2.86$, $p < 0.05$	–	–
Targets/new					
IT	$F_{1,15} = 8.97$, $p < 0.01$	$F_{1,15} = 18.27$, $p = 0.001$	–	–	–
IT x HM	–	$F_{1,15} = 4.71$, $p < 0.05$	–	–	–
IT x AP	–	–	–	–	$F_{1.5,23.1} = 5.06$, $p < 0.05$
IT x AP x ST	$F_{2.1,31.5} = 4.26$, $p < 0.05$	$F_{1.7,24.8} = 6.53$, $p < 0.01$	–	$F_{1.9,28.2} = 3.91$, $p < 0.05$	–
IT x HM x AP x ST	–	–	$F_{3.2,48.6} = 4.16$, $p < 0.01$	–	–
Non-targets/new					
IT x HM	–	–	$F_{1,15} = 14.64$, $p < 0.005$	$F_{1,15} = 14.83$, $p < 0.005$	$F_{1,15} = 11.64$, $p < 0.005$
IT x AP	$F_{1.4,21.3} = 4.95$, $p < 0.05$	–	–	–	–
IT x ST	–	–	–	–	$F_{1.0,15.6} = 5.51$, $p < 0.05$
IT x HM x AP	–	–	–	$F_{1.5,23.0} = 4.66$, $p < 0.05$	$F_{1.7,25.8} = 3.89$, $p < 0.05$
IT x HM x ST	–	–	$F_{1.2,18.1} = 4.09$, $p = 0.05$	$F_{1.3,19.5} = 8.44$, $p < 0.01$	–
IT x AP x ST	–	–	$F_{2.1,31.8} = 5.94$, $p < 0.01$	$F_{2.5,37.8} = 3.19$, $p < 0.05$	–
Targets/non-targets					
IT	$F_{1,15} = 4.66$, $p < 0.05$	–	–	–	–
IT x HM	–	–	$F_{1,15} = 8.43$, $p = 0.01$	$F_{1,15} = 13.51$, $p < 0.005$	$F_{1,15} = 4.92$, $p < 0.05$
IT x AP	$F_{1.6,23.3} = 16.99$, $p < 0.001$	$F_{1.2,18.4} = 4.55$, $p < 0.05$	–	–	–
IT x AP x ST	$F_{2.6,39.4} = 4.72$, $p < 0.01$	$F_{2.7,40.6} = 3.85$, $p < 0.05$	–	–	–

IT = item type; HM = hemisphere; AP = location; ST = site.

failed to give rise to any significant effects of item in either condition, results for this latency region are omitted from these tables. When the overall ANOVA gave rise to significant effects of item, subsidiary ANOVAs were conducted to separately contrast ERPs to targets, non-targets and new items with each other. A second set of global ANOVAs were conducted in order to directly contrast reliable target and non-target old/new effects as a function of condition. These were conducted on difference scores (old-new) rather than raw amplitude data and employed the factors of condition, hemisphere, location and site. A third set of global analyses compared correctly rejected new items across condition, employing the factors of condition, hemisphere, location and site. For this latter set of analyses, only those revealing significant effects involving the factor of condition will be reported. Additional *a priori* analyses were conducted on data from mid-frontal sites within the 300-500 msec latency region, from lateral parietal sites within the 500-800 msec latency region and from lateral frontopolar sites during the 1100-1400 msec and 1400-1900 msec latency regions. These analyses employed the factors of condition and item, as well as hemisphere and / or site. Any significant effects involving the factors of condition or item were further investigated with subsidiary ANOVAs to contrast ERPs to targets and non-targets with ERPs to new items as well as with each other. All *a priori* analyses also compared correctly rejected new items across condition – as with the global analyses, only analyses revealing significant effects involving the factor of condition will be reported. Finally, differences in the scalp topography of reliable target and non-target old/new effects were investigated, when appropriate, both

within and across condition. Topographic analyses were conducted on difference scores (old-new) derived from all 29 electrodes, as described in Chapter 4.

Magnitude analyses

100-300 msec

Picture condition: The global analysis revealed an item x hemisphere interaction. Pairwise contrasts between old and new items revealed a main effect of item for targets but no significant old/new effects for non-targets. For the target/non-target contrast, there were item x hemisphere and item x hemisphere x site interactions. These effects reflect a positive-going old/new effect for targets only, and greater positivity for targets, in comparison to non-targets, maximally, over left mid-lateral sites.

Word condition: ANOVA gave rise to a main effect of item and an item x hemisphere interaction. Pairwise contrasts between targets and new items revealed a main effect of item and an item x location x site interaction, the latter interaction also being found for the target/non-target contrast. There were no significant old/new effects for non-targets. These effects reflect positive old/new effects for targets only, maximal over superior temporal sites, and greater positivity for targets in comparison to non-targets over frontal and temporal locations, maximally, over superior frontal sites.

Between condition: ANOVA contrasting target old/new effects across condition revealed an interaction between condition, hemisphere, location and site [$F(2.6,39.0) = 3.07$, $p < 0.05$], reflecting larger old/new effects for targets from the word condition over the right hemisphere, maximally and significantly at the right mid-lateral temporal site.

300-500 msec

Picture condition: The global analysis revealed a main effect of item as well as a number of interactions, including item x location, item x site and item x hemisphere x site. Old/new contrasts gave rise to a main effect of item and an item x site interaction for targets, and an item x location interaction for non-targets. For the target/non-target contrast, a number of significant item effects were found, including a main effect as well as interactions with hemisphere, with location and with hemisphere and site. These findings reflect positive-going old/new effects for both types of old item, maximal over superior sites for targets and confined to parietal sites for non-targets [$F(1,15) = 5.75$, $p < 0.05$]. Additionally, ERPs to targets were more positive than those to non-targets at frontal and temporal locations, as well as over the left hemisphere, maximally at left mid-lateral sites.

Word condition: ANOVA gave rise to a main effect of item and an item x location x site interaction. Pairwise contrasts between old and new items found no significant old/new effects for non-targets, although, for targets, there was a main effect of item, as well as interactions between item and hemisphere, and between item, location and site. The target/non-target contrast revealed interactions between item and location, and between item, location and site. These findings reflect positive-going old/new effects for targets only, which are greater over the left, compared to the right, hemisphere, and greater positivity for targets, compared to non-targets, over frontal and temporal locations. The effects for both sets of contrasts were maximal over superior frontal sites.

Between-condition: The global analysis contrasting target old/new effects across condition failed to give rise to any significant effects involving the factor of condition.

Mid-frontal sites: The *a priori* analysis conducted on data from mid-frontal sites for the three item types across condition gave rise to a main effect of item [$F(1.8,27.0) = 14.14$, $p < 0.001$]. Main effects of item were found for the contrasts between targets and new items [$F(1,15) = 22.83$, $p < 0.001$] and between targets and non-targets [$F(1,15) = 13.30$, $p < 0.005$]. There were no significant effects for the contrast between non-targets and new items. These findings reflect, across condition, positive old/new effects for targets only (see figure 5.4), and greater positivity for targets compared to non-targets.

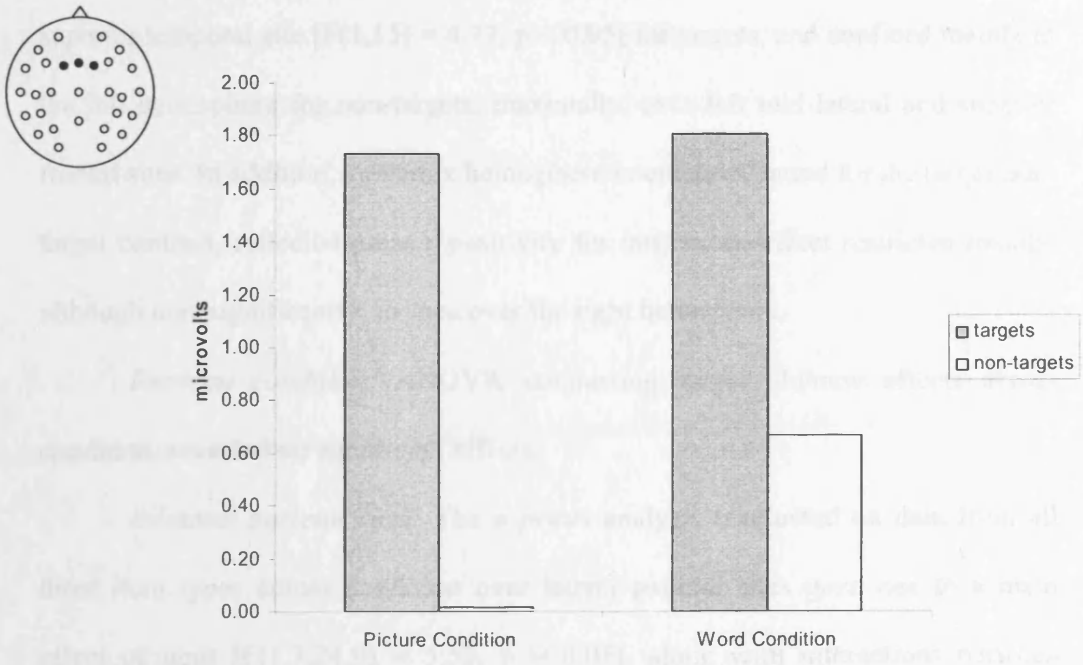

Figure 5.4.
Exp. 1 – Mean amplitudes (μV) of target and non-target old/new effects for the picture condition (left) and the word condition (right) over the 300-500 msec latency region. The mean amplitudes are collapsed across the three mid-frontal sites as indicated.

500-800 msec

Picture condition: The global analysis revealed a main effect of item and an item x site interaction. The same pattern of effects was evident for contrasts between targets and new items, as well as between targets and non-targets, reflecting greater positivity for targets compared to both non-targets and new items, effects which were maximal over superior sites. No reliable old/new effects were found for the contrast between non-targets and new items.

Word condition: The global analysis revealed a number of significant item effects, including interactions with hemisphere, with location and site and with hemisphere, location and site. Old/new contrasts revealed interactions between item, hemisphere, location and site for targets and between item and hemisphere, item, hemisphere and site, and item, location and site for non-targets. These findings reflect positive old/new effects for both items, reliable only at the right superior temporal site [$F(1,15) = 4.77$, $p < 0.05$] for targets, and confined mainly to the left hemisphere for non-targets, maximally, over left mid-lateral and superior frontal sites. In addition, an item x hemisphere interaction, found for the target/non-target contrast, reflected greater positivity for targets, an effect restricted mainly, although non-significantly, to sites over the right hemisphere.

Between condition: ANOVA contrasting target old/new effects across condition, revealed no significant effects.

Bilateral parietal sites: The *a priori* analysis conducted on data from all three item types across condition over lateral parietal sites gave rise to a main effect of item [$F(1.7,24.9) = 5.52$, $p = 0.01$], along with interactions between condition, item and hemisphere [$F(1.9,29.2) = 4.10$, $p < 0.05$] as well as between

condition, item and site [$F(2.7,40.5) = 3.57$, $p < 0.05$]. The contrast between targets and new items revealed a main effect of item [$F(1,15) = 9.06$, $p < 0.01$], an item x site interaction [$F(1.4,21.3) = 6.60$, $p = 0.01$] and a condition x item x site interaction [$F(1.3,20.0) = 4.34$, $p < 0.05$]. Subsidiary analysis found no significant differences between ERPs to targets and new items from the word condition. For the picture condition, subsidiary analysis revealed a main effect of item [$F(1,15) = 11.48$, $p < 0.005$] and an interaction between item and site [$F(1.2,17.4) = 7.18$, $p = 0.01$], indicating that parietal ERPs to targets were significantly more positive than those to new items in the picture condition, an effect that was maximal, bilaterally, over mid-lateral sites. The contrast between non-targets and new items gave rise to an item x hemisphere interaction [$F(1,15) = 10.92$, $p = 0.005$], a condition x item x hemisphere interaction [$F(1,15) = 7.13$, $p < 0.05$], and a condition x item x site interaction [$F(1.5,23.0) = 3.99$, $p < 0.05$]. Subsidiary analysis found no significant differences between non-targets and new item ERPs from the picture condition. However, for non-targets and new items from the word condition, subsidiary analysis revealed an interaction between item and hemisphere [$F(1,15) = 15.19$, $p = 0.001$], reflecting that, while there were no significant differences between ERPs to these items over the right hemisphere, left parietal ERPs to non-targets were significantly more positive than those to new items [$F(1,15) = 4.48$, $p = 0.05$]. Figure 5.5 shows the mean amplitudes of target and non-target old/new effects for the picture condition and the word condition over the 500-800 msec latency region collapsed across the three left parietal sites (46, 30, 29). The target/non-target contrast revealed a main effect of item [$F(1,15) = 4.99$, $p < 0.05$] and an item x site

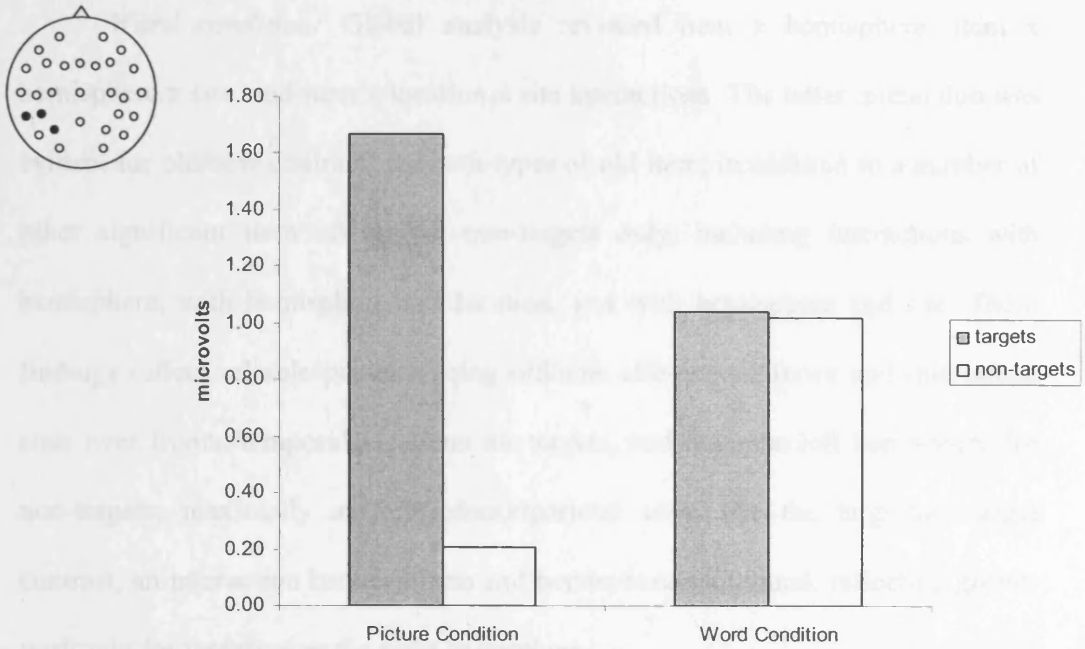

Figure 5.5.
Exp. 1 – Mean amplitudes (μV) of target and non-target old/new effects for the picture condition (left) and the word condition (right) over the 500-800 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

interaction [$F(1.9,28.1) = 7.39$, $p < 0.005$], reflecting greater positivity for targets, across condition, bilaterally, over mid-lateral and superior sites.

900-1100 msec

Picture condition: ANOVA revealed a main effect of item and an item x location interaction. The same effects were evident for the target/non-target contrast, reflecting greater positivity for targets over frontal and temporal locations. Old/new contrasts gave rise to a main effect of item and an item x site interaction for targets, and, for non-targets, interactions between item and location, as well as between item, hemisphere and location. These findings reflect positive-going old/new effects for both types of old item, maximal over superior sites for targets and confined to left parietal sites for non-targets [$F(1,15) = 7.47$, $p < 0.05$].

Word condition: Global analysis revealed item x hemisphere, item x hemisphere x site, and item x location x site interactions. The latter interaction was evident for old/new contrasts for both types of old item, in addition to a number of other significant item effects for non-targets only, including interactions with hemisphere, with hemisphere and location, and with hemisphere and site. These findings reflect reliable positive-going old/new effects at inferior and mid-lateral sites over frontal/temporal locations for targets, and over the left hemisphere for non-targets, maximally at left inferior/parietal sites. For the target/non-target contrast, an interaction between item and hemisphere was found, reflecting greater positivity for targets over the right hemisphere.

Between condition: ANOVA for the target old/new contrast across condition revealed a condition x site interaction [$F(1.2,18.3) = 4.82$, $p < 0.05$], reflecting the fact that, while positive-going old/new effects are evenly distributed across sites for targets from the word condition, these effects are maximally focused over superior sites for targets from the picture condition. Analysis for the non-target old/new contrast across condition revealed a number of condition effects including interactions with hemisphere [$F(1,15) = 7.30$, $p < 0.05$], with hemisphere and site [$F(1.4,21.3) = 5.18$, $p < 0.05$] as well as with location and site [$F(2.2,33.7) = 4.08$, $p < 0.05$], reflecting larger positive-going old/new effects for non-targets from the word condition over all left hemisphere sites and, bilaterally, over frontal and inferior temporal sites, an effect which was maximal and significant only over left inferior sites [$F(1,15) = 5.79$, $p < 0.05$].

1100-1400 msec

Picture condition: The global analysis revealed an item x location interaction, evident also for the target/non-target contrast, reflecting greater positivity for targets over frontal locations. The old/new contrast for non-targets revealed an item x hemisphere x location interaction, reflecting a relatively greater positivity for non-targets over all locations, except over left frontal sites where there was greater negativity for the same items. These non-target old/new effects did not reach significance at any left/right location, and there were no reliable old/new effects found for the contrast between targets and new items.

Word condition: ANOVA revealed an item x hemisphere interaction, an effect also evident for the target/non-target contrast. Old/new contrasts revealed an item x location interaction for targets and a number of item effects for non-targets, including interactions with hemisphere, with site, and with hemisphere and location. For targets, these findings reflect positive old/new effects over frontal locations, and greater positivity over the right hemisphere in comparison to non-targets. For non-targets, the findings reflect old/new effects that are positive-going over the left hemisphere, maximally at left temporal sites, but more negative-going over superior and right hemisphere sites.

Bilateral frontopolar sites: Grand average waveforms from frontopolar sites are shown in figures 5.6 and 5.7 for the picture and word conditions respectively. The focused analysis conducted on data from frontopolar sites for the three item types across condition revealed a main effect of item [$F(1.6,23.8) = 9.35$, $p < 0.005$], along with interactions between item, hemisphere and site [$F(1.6,24.7) = 3.62$, $p = 0.05$] as well as between condition, item, hemisphere and site

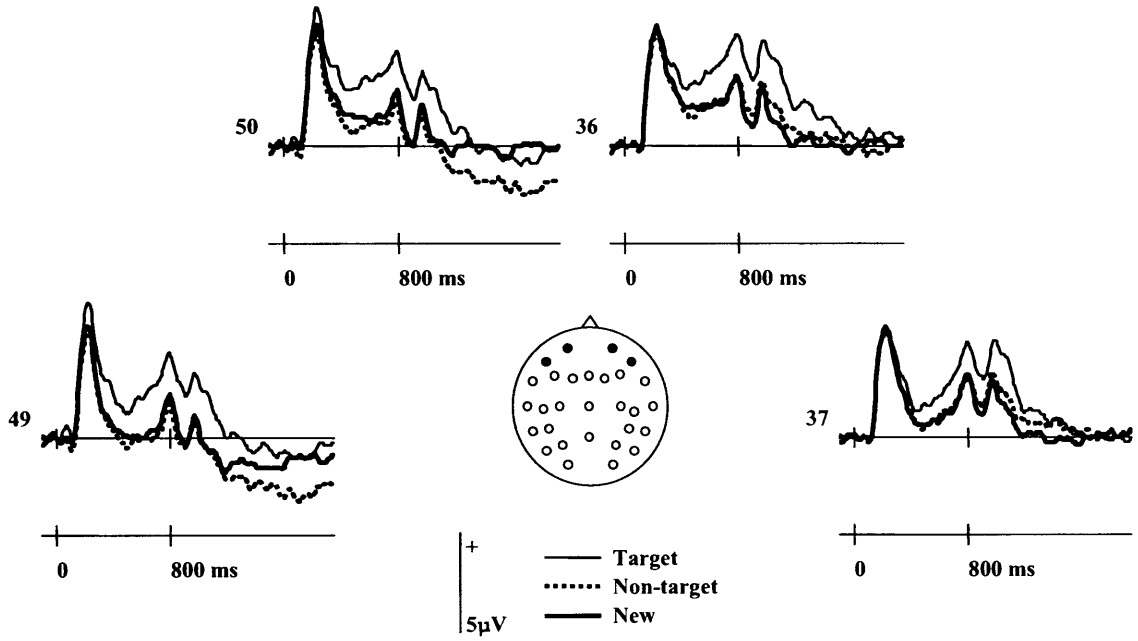

Figure 5.6.
Exp. 1 – Picture condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontopolar sites (49, 50, 37, 36).

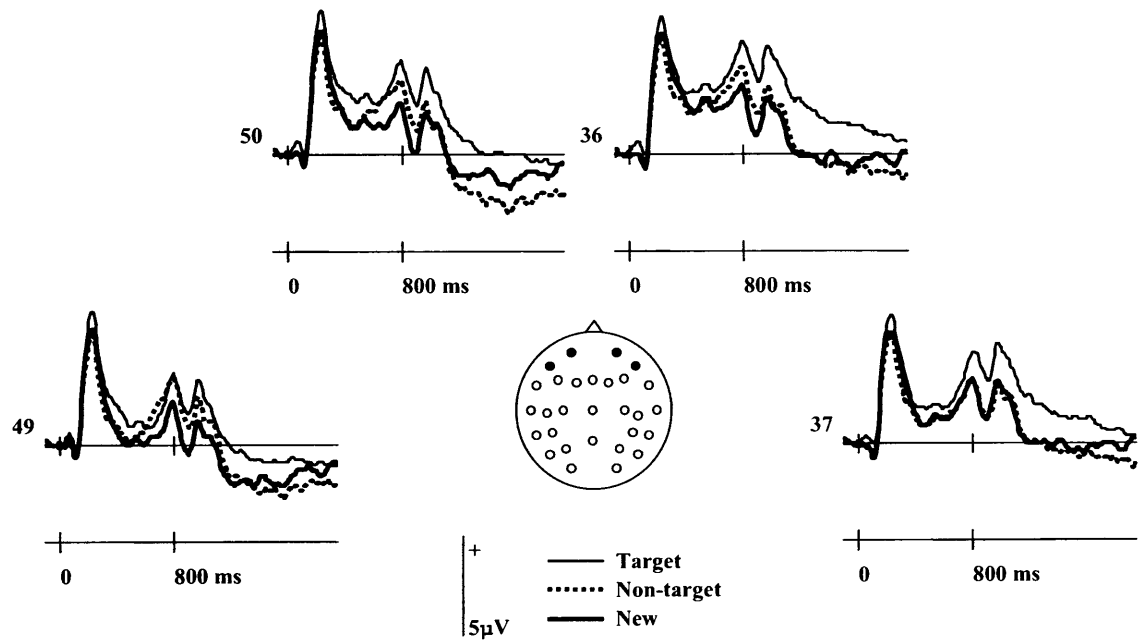

Figure 5.7.
Exp. 1 – Word condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontopolar sites (49, 50, 37, 36).

[F(1.7,25.4) = 5.04, $p < 0.05$]. The contrast between targets and new items revealed a main effect of item [F(1,15) = 11.74, $p < 0.005$], indicating, across condition, that frontopolar ERPs to targets were significantly more positive than those to new items. The contrast between non-targets and new items gave rise to a condition x item x hemisphere interaction [F(1,15) = 5.01, $p < 0.05$] and an item x hemisphere x site interaction [F(1,15) = 8.58, $p = 0.01$]. Subsidiary analyses revealed interactions between item and hemisphere [F(1,15) = 20.95, $p < 0.001$] for the picture condition, and between item, hemisphere and site [F(1,15) = 9.39, $p < 0.01$] for the word condition. These findings reflect, for the picture condition, greater positivity for non-targets over right frontopolar sites but greater positivity for new items over left frontopolar sites. For the word condition, these findings indicated greater positivity for non-targets at left superior and right inferior sites, but greater positivity for new items at left inferior and right superior sites. These non-target old/new effects, however, did not reach significance in either condition. The target/non-target contrast revealed a main effect of item [F(1,15) = 10.95, $p = 0.005$], an item x site interaction [F(1,15) = 9.27, $p < 0.01$] and a condition x item x hemisphere x site interaction [F(1,15) = 7.96, $p < 0.01$]. Subsidiary analysis revealed, for the picture condition, a main effect of item [F(1,15) = 5.98, $p < 0.05$] and an item x hemisphere x site interaction [F(1,15) = 8.98, $p < 0.01$], reflecting significantly greater frontopolar positivity for targets, maximally at the inferior site over the left hemisphere but at the superior site over the right hemisphere. For the word condition, subsidiary analysis revealed a main effect of item [F(1,15) = 8.18, $p = 0.01$] and an item x site interaction [F(1,15) = 10.68, $p = 0.005$], reflecting

greater positivity for targets over frontopolar locations, maximal over superior frontopolar sites.

1400-1900 msec

Picture and word conditions: ANOVAs revealed no significant effects involving the factor of item.

Bilateral frontopolar sites: The *a priori* analysis conducted on data from frontopolar sites for the three item types across condition revealed a main effect of item [$F(1.4,21.1) = 9.23$, $p < 0.005$], along with interactions between item and hemisphere [$F(1.6,24.6) = 3.62$, $p = 0.05$], condition, item and hemisphere [$F(1.9,29.0) = 4.48$, $p < 0.05$] and condition, item, hemisphere and site [$F(1.9,27.9) = 5.23$, $p = 0.01$]. The contrast between targets and new items gave rise to a main effect of item [$F(1,15) = 8.91$, $p < 0.01$], an item x hemisphere x site interaction [$F(1,15) = 5.41$, $p < 0.05$] and a condition x item x hemisphere x site interaction [$F(1,15) = 4.54$, $p = 0.05$]. For the picture condition, the subsidiary analysis revealed an item x hemisphere x site interaction [$F(1,15) = 11.44$, $p < 0.005$], reflecting greater positivity for targets over most frontopolar sites, except at the left superior frontopolar site where there was greater positivity for new items. These target old/new effects from the picture condition did not reach significance at any site. For the word condition, the subsidiary analysis found a main effect of item [$F(1,15) = 7.74$, $p = 0.01$], reflecting a significant positive-going old/new effect for targets from the word condition. The contrast between non-targets and new items gave rise to a main effect of item [$F(1,15) = 5.35$, $p < 0.05$], as well as interactions between item and hemisphere [$F(1,15) = 13.57$, $p < 0.005$] and condition, item and hemisphere [$F(1,15) = 7.03$, $p < 0.05$]. Subsidiary analyses revealed, for the picture

condition, a main effect of item [$F(1,15) = 4.95$, $p < 0.05$] as well as an interaction between item and hemisphere [$F(1,15) = 21.81$, $p < 0.001$], but no significant effects involving the factor of item for the word condition. These findings reflect, for the picture condition only, a negative-going old/new effect, significant over left frontopolar sites. The target/non-target contrast revealed a main effect of item [$F(1,15) = 11.52$, $p < 0.005$], a condition x item x hemisphere interaction [$F(1,15) = 6.47$, $p < 0.05$] and a condition x item x hemisphere x site interaction [$F(1,15) = 12.89$, $p < 0.005$]. For the picture condition, subsidiary analysis gave rise to an item x hemisphere interaction [$F(1,15) = 5.42$, $p < 0.05$] and an item x hemisphere x site interaction [$F(1,15) = 14.44$, $p < 0.005$], reflecting significantly greater frontopolar positivity for targets over the left hemisphere, and a slightly greater positivity for non-targets at the right inferior frontopolar site, although this latter effect was not significant. For the word condition, the subsidiary analysis revealed a main effect of item [$F(1,15) = 11.03$, $p = 0.005$] and an item x site interaction [$F(1,15) = 6.54$, $p < 0.05$], reflecting greater positivity for targets over frontopolar locations, maximal over the superior sites.

Topographic analyses

Analyses of scalp topography proceeded in two stages. First, the distribution of target and non-target old/new effects were compared across condition. These analyses were conducted within the latency regions in which significant interactions between condition and scalp location were revealed for the magnitude analyses comparing old/new differences across condition. These latency regions included 100-300 and 900-1100 msec for targets and 900-1100 msec for non-targets. Second, the distribution of reliable target and non-target old/new

effects were contrasted within each condition. These analyses were conducted within the latency regions in which the magnitude analyses indicated differences in the distribution of old/new effects across item type. These latency regions included 300-500 and 900-1100 msec for the picture condition, and 500-800, 900-1100 and 1100-1400 msec for the word condition. The first set of analyses, employing the factors of condition and site, provided no evidence that the scalp distribution of old/new effects varied according to condition given the lack of any significant interactions between condition and site for targets in the 300-500 and 900-1100 msec latency regions and for non-targets in the 900-1100 msec latency region. The second set of analyses, employing the factors of item, site and latency region, revealed, for the picture condition, a significant item x site interaction [$F(3.0,45.0) = 4.77$, $p < 0.01$] and, for the word condition, significant interactions between latency region and site [$F(4.4,66.2) = 2.73$, $p < 0.05$] as well as between item type and site [$F(4.2,63.2) = 3.32$, $p = 0.01$]. As can be seen in figure 5.8, the differences in scalp distribution between target and non-target old/new effects in the picture condition are similar for the two latency regions, with positive-going old/new effects maximally distributed over mid-central / mid-frontal sites for targets, and over temporo-parietal / parieto-occipital sites for non-targets. However, for the word condition, target and non-target old/new distributions evolve across the three latency regions. For targets, these develop from a positive mid-central maximum over the 500-800 msec latency region through to a positive right frontopolar and negative central parietal maxima over the 1100-1400 msec latency region. For non-targets, these evolve from a positive left parietal and mid-frontal maxima over the

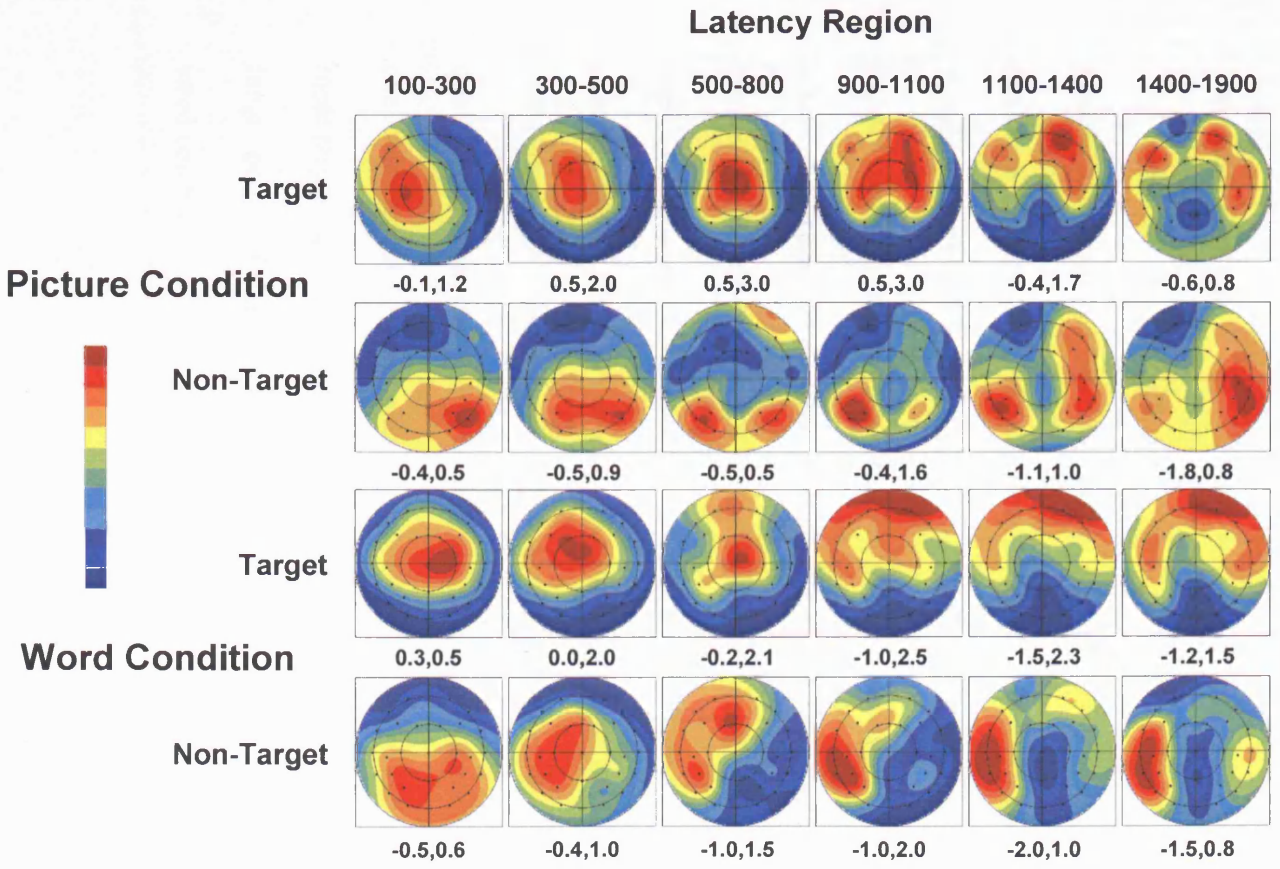

Figure 5.8.
Exp. 1 – Topographic maps of target and non-target old/new effects in the picture condition and the word condition for all latency regions as indicated. The paired values below each map indicate the voltage ranges (microvolts) of the differences between the two types of item (i.e., old-new) and can be interpreted with reference to the bar presented on the far left of the figure.

500-800 msec latency region through to a positive left temporo-parietal and negative central parietal maxima over the 1100-1400 msec latency region.

Summary of results

During the 100-300 msec latency region, ERPs to targets were more positive than those to both non-targets and new items across condition. For both conditions, targets, but not non-targets, elicited an early mid-frontal old/new effect during the 300-500 msec latency region. During the same latency region, for the picture condition only, non-targets elicited an early bilateral parietal old/new effect which dissociated topographically from the early mid-frontal effect elicited by targets. A left parietal old/new effect was evident during the 500-800 msec latency region for non-targets from the word condition only. However, a later-onsetting left parietal old/new effect was elicited by non-targets from both conditions during the 900-1100 msec latency region. For both conditions, this latter effect differed qualitatively from positive-going old/new effects for targets, distributed maximally over mid-frontal / frontopolar sites. During the 1100-1400 msec latency region, these target old/new effects were evident over frontopolar sites, but continued for a longer period of time, into the 1400-1900 msec latency region, for targets from the word condition.

Discussion

Behaviour

As expected, across condition, response accuracy was lower for targets than for both non-targets and new items, reflecting poor memory for targets, presumably due to their shallow encoding. In this case, it would seem likely that targets were often endorsed on the basis of their familiarity. Responses to new items were also more accurate than were those to non-targets for both conditions, indicating that there was greater difficulty in discriminating targets from non-targets than in discriminating targets from new items. While new items could be discriminated from targets on the basis of a lack of familiarity, as targets and non-targets should both be familiar, discrimination of these items would have required further information to differentiate their sources. This is supported, in the word condition only, by the finding of quicker responses to new items than to both targets and non-targets, consistent with previous findings that participants are able to make discriminations based on familiarity more quickly than discriminations requiring the retrieval of source information (e.g., Gronlund, Edwards & Ohrt, 1997; Hintzman *et al.*, 1998).

However, such RT differences were not found between items in the picture condition, and RTs for targets and non-targets were significantly shorter in the picture condition compared to those in the word condition. This suggests that, while targets and non-targets from the picture condition were discriminated with a relatively high level of efficiency, discrimination between targets and non-targets in the word condition required additional processing resources. According to proponents of the source monitoring framework, different memory attributes may

revive and differentiate at different rates (Johnson, Hashtroudi & Lindsay, 1993). It is possible that the discrimination of targets and non-targets in the picture condition, given their distinct modalities, required relatively less specified source information which could be more rapidly retrieved compared to that required for the target/non-target discrimination in the word condition.

ERPs

During the earliest latency region employed (100-300 msec), ERPs to targets in both conditions were more positive-going than ERPs to non-targets and new items. These unexpected findings suggest that, across condition, targets were discriminated from both non-targets and new items within 300 msec post-stimulus. Although not usually observed in study-test recognition paradigms, there have been similar reports of early (100-300 msec) old/new effects in studies that have employed recognition tests. However, whereas, in the present experiment, these early effects were topographically quite widespread, these have previously been reported over frontopolar locations. These effects have been observed for items studied in a visual, as opposed to an auditory, modality (Curran & Dien, 2003), for pseudo-words rather than words (Curran, 1999) and for visually complex stimuli (Tsivilis *et al.*, 2001). In the present experiment, this early effect seems to be sensitive to shallowly-encoded words as opposed to deeply-encoded words and pictures. It is thought that this early modulation is sensitive to repetition and has been proposed to support recognition memory (Tsivilis *et al.*, 2001). However, it is far from certain what the functional significance of this early modulation might be. In the present experiment, this effect did not seem to be sufficient to allow

target/non-target discrimination, otherwise RTs for these items would not have differed between picture and word conditions.

As predicted, between 500-800 msec post-stimulus, correctly rejected non-targets from the word condition elicited a left parietal old/new effect. This effect was not elicited by targets from the same condition – it seems that these shallowly-encoded words could not be identified on the basis of retrieved information diagnostic of their study source and, therefore, it was necessary to recall non-target source information in order to reject non-target items. These findings concur with those of Herron and Rugg (2003a) who found that, when memory for targets was poor, the correct rejection of non-targets required the retrieval of non-target study source. For the picture condition, the left parietal old/new effect was absent for non-targets until the 900-1100 msec latency region. At a latency of 900 msec post-stimulus, it is doubtful that this effect could reflect processes supporting retrieval of information to be used for response selection in this experiment. First, considering mean RT for non-targets in the picture condition was 1113 msec, motor responses in relation to such decisions are likely to have been initiated by 900 msec. Furthermore, if target/non-target discrimination was based on non-target recollection in both conditions, as the left parietal old/new effect was evident at a later time for non-targets from the picture condition, RTs should have been shorter, not longer, for non-targets from the word condition. Therefore, it would seem unlikely that non-target recollection, as reflected by the left parietal old/new effect, provided the basis for target/non-target discrimination in the picture condition.

For targets from the picture condition, positive old/new effects were found at parietal sites during the 500-800 msec latency region. However, as this positivity

was bilateral, it is doubtful that this effect reflects recollective processing as typified by the 'classical' left-lateralised parietal old/new effect for verbal memories (Friedman, 2000). It is more likely that this bilateral effect is related to the well known parietal positivity (the 'P300' or 'P3b') associated with low probability, high 'target value' stimuli, and which occurs independently of memory processes (e.g., Donchin & Coles, 1988). Although the spatial and temporal characteristics of the P300 overlap with the left parietal old/new effect, recent findings have shown that this latter effect is uninfluenced by the relative probability of old and new items (Herron, Quayle & Rugg, 2003). So, how were participants able to discriminate between targets and non-targets in the picture condition if recollection did not occur for either item within a timescale that corresponded with correct responses? During the 300-500 msec latency region, targets elicited an old/new effect with a scalp distribution consistent with an early mid-frontal effect thought to reflect familiarity processing. Although non-targets from the same condition did not elicit an early mid-frontal effect, these items elicited a positive old/new effect over bilateral parietal sites during the same latency region. This non-target old/new effect was found to differ qualitatively from that elicited by targets, indicating that, for the picture condition, the processes elicited by targets and non-targets during this latency region were functionally distinct.

An old/new effect with a similar scalp distribution over parietal sites during the 300-500 msec latency region has been previously linked to a perceptually-based implicit memory process (Friedman, 2004; Rugg *et al.*, 1998). Given that such implicit memory processes are thought to be sensitive to the degree of perceptual

match between an item's initial and subsequent encounter (Roediger & McDermott, 1993), study and test items presented in different modalities should weaken implicit memory. In the present experiment, as a format change occurred between study and test for non-targets from the picture condition, rather than the word condition, and if the bilateral parietal old/new effect during the 300-500 msec latency region reflects a perceptually-based implicit memory mechanism, this early parietal effect should have been greater for non-targets from the word condition. As this ERP effect only occurred for non-targets from the picture condition, however, it can be concluded that this does not reflect a perceptually-based implicit memory process.

Although measured within a slightly later latency region (400-600 msec post-stimulus), a recent study (Schloerscheidt & Rugg, 2004) also reported findings of a positive old/new effect over bilateral parietal sites when correctly recognised words had been studied as pictures but not when they had been studied as words. In the present experiment, given that this effect occurred only for test words associated with studied pictures, one possibility is that this reflects the relatively rapid retrieval of non-target pictorial information. Certainly, as proposed by proponents of the source monitoring framework (Johnson *et al.*, 1993), memory for different types of information has been found to revive at different times (e.g., Johnson, Kounios & Reeder, 1994). Furthermore, as pictorial information relating to non-targets would have been particularly salient, it might be expected that decisions based on such information could be executed quickly and heuristically (Johnson *et al.*, 1993), explaining the differences in target and non-target RTs between the conditions in the present experiment. Whatever the functional

significance of the early bilateral parietal positivity, both the ERP and behavioural evidence suggest that the signals produced by targets and non-targets from the picture condition were distinct enough to allow for their discrimination at this very early time-point.

For both conditions, between 1100-1400 msec, a positive old/new effect over bilateral frontopolar regions was observed for targets, an effect not evident for non-targets. Late-onsetting frontal effects are usually reported as being right lateralised, although they have also previously been reported as being bilaterally distributed over frontal and pre-frontal regions (Ranganath & Paller, 2000; Senkfor & Van Petten, 1998). It must also be noted that, while the asymmetry was not statistically significant, the frontal old/new effect in the present experiment was, in fact, larger in amplitude over the right hemisphere. This late frontal old/new effect has been thought to reflect the monitoring and evaluation of the products of retrieval *success* (e.g., Wilding & Rugg, 1996), the strategic search for source-specifying information (e.g., Senkfor & Van Petten, 1998) and the strategic monitoring and evaluation of the products of a retrieval *attempt* (e.g., Rugg *et al.*, 2000). Given this latter view, the late frontal effect is not contingent upon, nor is it an obligatory consequence of, recollection. The finding of a double dissociation in the present experiment is consistent with this view – whereas targets elicited late frontal but no left parietal effects, non-targets elicited left parietal but no late frontal effects. These findings also concur with the notion that the products of a retrieval attempt for items that elicit vivid recollection should require less monitoring and evaluation than those for items associated with poor recall (Rugg *et al.*, 2000). If it is correct that the late frontal old/new effect does reflect monitoring

operations, then it might be expected that the efficient discrimination of targets from non-targets in the picture condition would lead to a reduced late frontal effect for targets in this condition. However, the lack of a dissociation between conditions provides little support for the notion that targets from the word condition required a greater degree of monitoring prior to responding in comparison to targets in the picture condition.

Conclusion

Experiment 1 investigated whether the ERP correlates of recollection would differ according to the retrieval strategies employed in two versions of an exclusion task. As predicted, the findings suggest that, for the word condition, discrimination of target and non-target items was based on non-target recollection. These findings are consistent with the notion that, when targets cannot be identified on the basis of retrieved information diagnostic of their study source, it is necessary to recall non-target source information in order to reject non-target items. In contrast, for the picture condition, there was no evidence to suggest that the discrimination of targets and non-targets was based on slow, intentional retrieval processes consistent with recollection for either item. Instead, this discrimination occurred at a relatively early time-point when functionally distinct sets of processes were engaged in identifying the two classes of items, providing a basis for source decisions to be executed quickly and heuristically.

Experiment 2

A second ERP experiment was conducted to determine whether target and non-target items are differentially discriminated according to whether non-target items are pictures or words when memory for targets is good. The design for Experiment 2 was identical to that employed in Experiment 1 with one exception: a pleasantness judgement task was employed to elicit good memory for targets. The predictions for the two conditions were identical. Given that memory for targets should be good, it was proposed that a retrieval strategy would be adopted such that targets will be identified on the basis of retrieved information diagnostic of their study source and non-targets will be identified on the basis of the absence of this information. Therefore, it was predicted that, for both conditions, correctly identified targets, but not non-targets, would elicit a left parietal old/new ERP effect.

Method

Participants

Eighteen participants were employed in this experiment. Data from 2 of the participants were discarded, one due to excessive blink saturation, and the other because of a technical failure occurring during EEG recording. The remaining 16 participants included 8 males and 8 females, with an overall age range of 18-25 years (mean age: 20 years).

Stimuli, Design and Procedures

The stimulus set, experimental design and procedures were identical to those employed in Experiment 1, apart from the target (list 2) study task, for which

participants were now required to verbally rate each word for pleasantness on a scale from 1 (unpleasant) to 5 (pleasant). EEG and EOG recording parameters, trial rejection criteria and blink correction procedures were identical to those employed in Experiment 1.

Results

Behavioural data

Table 5.4 shows the accuracy and reaction time data. A 2 (condition: picture, word) x 3 (item: target, non-target, new) repeated-measures ANOVA performed on the accuracy data gave rise to a main effect of item [$F(2,30) = 28.84$, $p < 0.001$] and a condition x item interaction [$F(2,30) = 10.16$, $p < 0.001$]. Bonferroni t-tests (adjusted alpha level: 0.017) revealed that non-target accuracy was higher for the picture condition than for the word condition [$t(15) = 4.04$, $p = 0.001$] but that target and new item accuracy did not vary according to condition. ANOVA performed on the RT data revealed a main effect of condition [$F(1,15) = 42.29$, $p <$

Tab 5.4.
Exp. 2 – Mean percent accuracy and reaction time (including standard deviations) for correctly classified targets, non-targets and new items as a function of condition.

CONDITION	ITEM TYPE	% CORRECT	RT (SD)
Picture	Targets	83 (10)	1097 (129)
	Non-targets	94 (6)	1120 (170)
	New	97 (3)	1050 (196)
Word	Targets	86 (8)	1263 (139)
	Non-targets	84 (9)	1334 (184)
	New	98 (2)	1070 (144)

0.001], a main effect of item [$F(2,30) = 37.03$, $p < 0.001$] and a condition x item interaction [$F(2,30) = 21.84$, $p < 0.001$]. Bonferroni t-tests (adjusted alpha level: 0.017) indicated that RTs to targets and non-targets from the picture condition were significantly faster than to those from the word condition [targets: $t(15) = 6.14$, $p < 0.001$; non-targets: $t(15) = 9.64$, $p < 0.001$], but that new item RTs did not differ as a function of condition. One-way within- subjects ANOVAs found main effects of item for the picture condition [$F(2,30) = 4.10$, $p < 0.05$] and for the word condition [$F(2,30) = 57.62$, $p < 0.001$]. Bonferroni t-tests (adjusted alpha level: 0.008) for the word condition revealed significantly longer RTs for targets ($t(15) = 3.80$, $p < 0.005$) and non-target items ($t(15) = 5.85$, $p < 0.001$) compared to new items but no significant difference between target and non-target items. All possible contrasts between items in the picture condition did not reach significance.

ERP data

The mean number (and range) of trials contributing to the ERPs associated with target, non-target and new items were 42 (22-55), 48 (26-56) and 50 (28-60) respectively for the picture condition and 45 (26-59), 43 (27-53) and 51 (28-60) respectively for the word condition. Grand average waveforms for picture and word conditions are shown in figures 5.9 and 5.10 respectively. These figures indicate similar patterns of ERP effects for both conditions. ERPs begin to clearly diverge from around 300 msec post-stimulus, with ERPs to targets, but not to non-targets, becoming more positive than those to new items. This target positivity seems to be left-lateralised and sustained for approximately 1100-1400 msec post-stimulus, and is larger for the picture condition than for the word condition. A

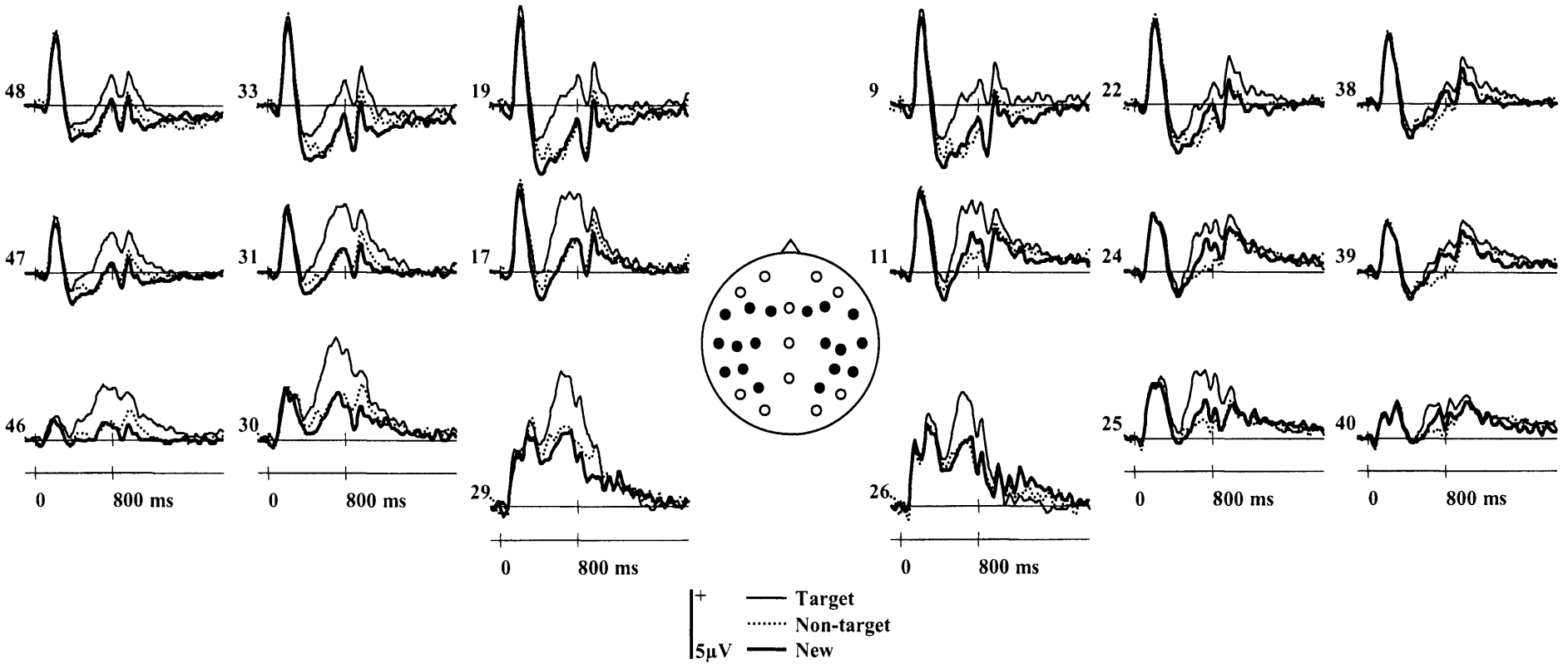

Figure 5.9.
Exp. 2 – Picture condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontal (48, 33, 19, 38, 22, 9), lateral temporal (47, 31, 17, 29, 24, 11) and lateral parietal sites (46, 30, 29, 40, 25, 26).

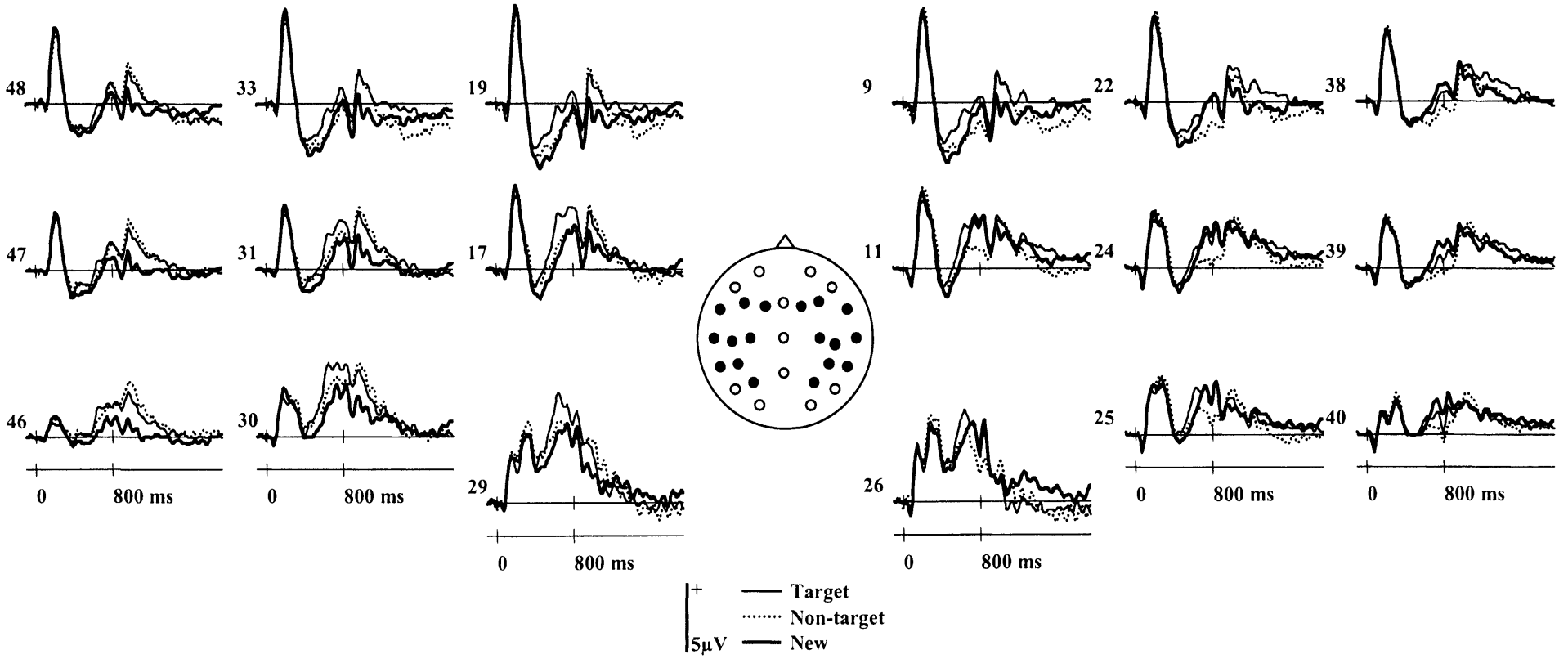

Figure 5.10.
Exp. 2 – Word condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at electrode sites as described in Figure 5.9.

short-lived, left parietal old/new effect is also apparent for non-targets from both conditions from approximately 900 msec post-stimulus.

ERP analyses proceeded in exactly the same way as described in Experiment 1. Initial global analyses of data from each condition are shown in tables 5.5 and 5.6. However, results for the 100-300 msec latency region for both conditions, as well as for the 300-500 msec latency region for the word condition, are omitted from these tables as the initial ANOVAs for the respective latency regions / conditions failed to give rise to significant effects of item.

Magnitude analyses

100-300 msec

Picture and word conditions: Initial global analyses revealed no significant effects involving the factor of item.

300-500 msec

Picture condition: The initial ANOVA revealed a main effect of item as well as an item x site interaction. These same effects were also found for the target old/new contrast, in addition to an interaction between item, location and site. The pairwise contrast between targets and non-targets gave rise to an item x site interaction. These findings reflect greater positivity for targets in comparison both to new items, maximally over superior frontal sites, and to non-targets, maximally, but non-significantly, over superior sites. No reliable old/new effects were evident for non-targets.

Word condition: ANOVA failed to give rise to any significant effects involving the factor of item.

Tab 5.5.
Exp. 2 – Summary of ANOVA results in each ERP latency region for the picture condition

	300-500 ec	500-800 ec	900-1100 ec	1100-1400 ec	1400-1900 ec
Targetsnon-targetsew					
IT	$F_{1.8,26.9} = 5.44$, $p = 0.01$	$F_{1.9,28.5} = 15.94$, $p < 0.001$	$F_{1.4,21.3} = 7.49$, $p < 0.01$	–	–
IT xM	–	–	$F_{1.6,23.5} = 6.10$, $p = 0.01$	–	–
IT xS	$F_{2.2,32.9} = 6.46$, $p < 0.005$	$F_{2.2,33.1} = 22.19$, $p < 0.001$	–	–	–
IT xR xS	–	$F_{2.9,43.4} = 2.78$, $p = 0.05$	–	$F_{3.0,45.2} = 4.59$, $p < 0.01$	$F_{3.0,44.4} = 3.02$, $p < 0.05$
Targetsew					
IT	$F_{1,15} = 11.65$, $p < 0.005$	$F_{1,15} = 20.73$, $p < 0.001$	$F_{1,15} = 8.90$, $p < 0.01$	–	–
IT xM	–	$F_{1,15} = 4.70$, $p < 0.05$	$F_{1,15} = 6.69$, $p < 0.05$	–	–
IT xR	–	–	–	$F_{1.3,19.4} = 4.78$, $p < 0.05$	–
IT xS	$F_{1.2,18.2} = 10.84$, $p < 0.005$	$F_{1.2,18.6} = 33.95$, $p < 0.001$	–	–	–
IT xR xS	$F_{1.8,26.5} = 4.14$, $p < 0.05$	–	–	$F_{1.8,26.8} = 6.67$, $p < 0.01$	$F_{1.9,28.2} = 4.20$, $p < 0.05$
Non-targetsew					
IT xM	–	–	$F_{1,15} = 11.99$, $p < 0.005$	–	–
Targetsnon-targets					
IT	–	$F_{1,15} = 22.17$, $p < 0.001$	$F_{1,15} = 12.52$, $p < 0.005$	–	–
IT xS	$F_{1.3,20.2} = 4.47$, $p < 0.05$	$F_{1.2,17.3} = 36.19$, $p < 0.001$	–	–	–
IT xR xS	–	$F_{1.9,28.3} = 7.84$, $p < 0.005$	$F_{2.7,40.4} = 3.62$, $p < 0.05$	–	–

IT = item type; HM = hemisphere; AP = location; ST = site.

Tab 5.6.
Exp. 2 – Summary of ANOVA results in each ERP latency region for the word condition

	500-800 ec	900-1100 ec	1100-1400 ec	1400-1900 ec
Targetsnon-targetsew				
T	$F_{1.8,26.8} = 3.96$, $p < 0.05$	–	–	–
T xM	$F_{1.5,22.6} = 11.15$, $p = 0.001$	$F_{1.6,23.8} = 11.65$, $p = 0.001$	–	–
T xR	–	–	$F_{2.3,34.5} = 3.15$, $p < 0.05$	–
T x5	$F_{1.9,29.2} = 7.98$, $p < 0.005$	–	–	$F_{1.8,26.9} = 6.89$, $p = 0.005$
T xMR	–	–	$F_{3.1,45.8} = 2.79$, $p = 0.05$	–
T xM5	$F_{3.1,47.1} = 2.73$, $p = 0.05$	$F_{1.7,26.0} = 3.46$, $p = 0.05$	–	–
Targetsew				
T	$F_{1,15} = 5.61$, $p < 0.05$	–	–	–
T xM	$F_{1,15} = 8.51$, $p = 0.01$	$F_{1,15} = 8.67$, $p = 0.01$	–	–
T xR	–	–	$F_{1.2,18.4} = 5.67$, $p < 0.05$	–
T x5	$F_{1.1,15.9} = 14.26$, $p = 0.001$	–	–	–
T xMR	–	–	$F_{1.9,28.9} = 3.54$, $p < 0.05$	–
T xR x5	–	–	$F_{1.7,25.7} = 4.41$, $p < 0.05$	–
Non-targetsew				
T xM	$F_{1,15} = 20.82$, $p < 0.001$	$F_{1,15} = 18.76$, $p = 0.001$	$F_{1,15} = 4.36$, $p = 0.05$	–
T x5	–	–	–	$F_{1.2,17.7} = 15.81$, $p = 0.001$
T xMR	–	–	$F_{1.6,23.4} = 4.93$, $p < 0.05$	$F_{1.5,22.4} = 5.72$, $p < 0.05$
T xM5	$F_{1.6,24.4} = 4.45$, $p < 0.05$	$F_{1.2,17.4} = 5.69$, $p < 0.05$	–	–
T xMR x5	–	–	–	$F_{2.8,42.7} = 2.80$, $p = 0.05$
Targetson-targets				
T	$F_{1,15} = 8.83$, $p = 0.01$	–	–	–
T x5	$F_{1.0,15.6} = 7.46$, $p = 0.01$	–	–	$F_{1.2,18.1} = 8.63$, $p < 0.01$

IT = item type; HM = hemisphere; AP = location; ST = site.

Mid-frontal sites: The focused analysis conducted on data from mid-frontal sites for the three item types across condition gave rise to a main effect of item [$F(1.7,25.8) = 8.10$, $p < 0.005$]. A main effect of item was found for the contrast between targets and new items [$F(1,15) = 22.55$, $p < 0.001$], reflecting positive old/new effects for targets across condition (see figure 5.11). There were no significant effects for the contrasts between targets and non-targets or between non-targets and new items.

500-800 msec

Picture condition: The global analysis gave rise to a main effect of item, an item x site interaction and an item x location x site interaction, the same pattern of effects that were also revealed for the target/non-target contrast. Old/new effects

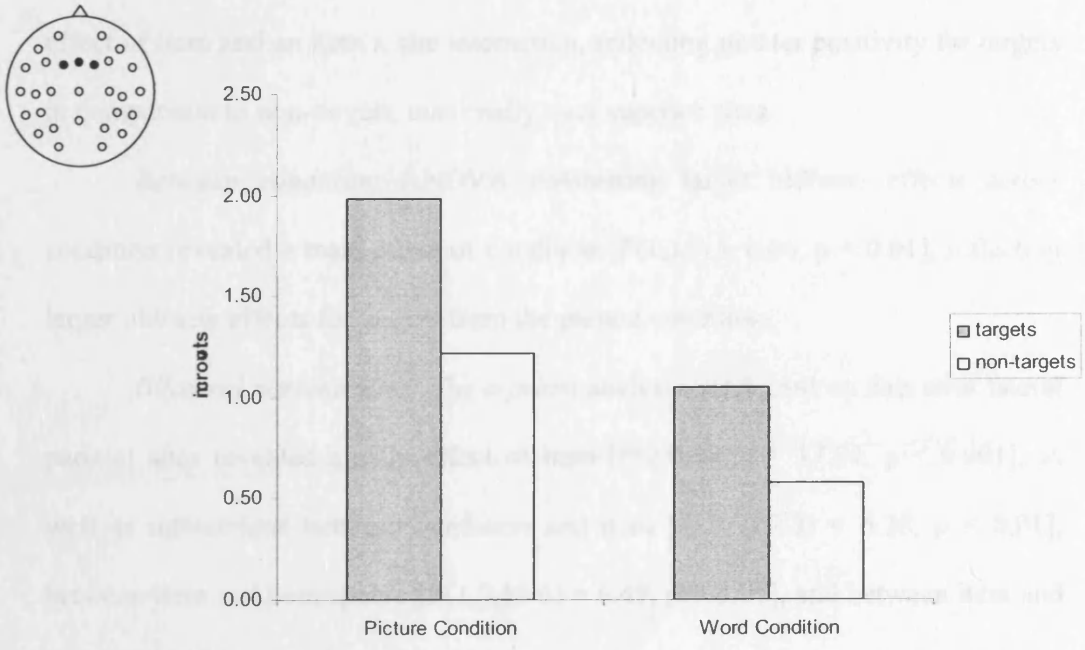

Figure 5.11.
Exp. 2 – Mean amplitudes (μV) of target and non-target old/new effects for the picture condition (left) and the word condition (right) over the 300-500 msec latency region. The mean amplitudes are collapsed across the three mid-frontal sites as indicated.

were evident for targets, but not non-targets, in the form of a main effect of item, as well as interactions between item and hemisphere, and between item and site. These findings reflect a positive-going old/new effect, for targets only, which is greater over the left than the right hemisphere, and greater positivity for targets in comparison to non-targets, both effects being maximal over superior sites.

Word condition: ANOVA revealed a number of significant effects of item, including a main effect, as well as interactions with hemisphere, with site, and with hemisphere and site. Old/new contrasts revealed, for targets, a main effect of item as well as interactions between item and hemisphere, and, for non-targets, item x hemisphere and item x hemisphere x site interactions. These findings reflect a positive-going old/new effect for targets, which is left-lateralised and maximal over superior sites, but a negative-going old/new effect for non-targets at right inferior sites. The pairwise contrast between targets and non-targets gave rise to a main effect of item and an item x site interaction, reflecting greater positivity for targets in comparison to non-targets, maximally over superior sites.

Between condition: ANOVA contrasting target old/new effects across condition revealed a main effect of condition [$F(1,15) = 8.06$, $p = 0.01$], reflecting larger old/new effects for targets from the picture condition.

Bilateral parietal sites: The *a priori* analysis conducted on data over lateral parietal sites revealed a main effect of item [$F(2.0,30.0) = 17.04$, $p < 0.001$], as well as interactions between condition and item [$F(1.8,27.3) = 6.38$, $p < 0.01$], between item and hemisphere [$F(1.3,19.6) = 6.49$, $p = 0.01$], and between item and site [$F(2.7,40.2) = 8.48$, $p < 0.001$]. The contrast between targets and new items revealed a main effect of item [$F(1,15) = 26.33$, $p < 0.001$], a condition x item

interaction [$F(1,15) = 10.41$, $p < 0.01$], an item x hemisphere interaction [$F(1,15) = 6.28$, $p < 0.05$] and an item x site interaction [$F(1.4,21.6) = 14.09$, $p < 0.001$], reflecting positive-going old/new effects for targets, larger for targets from the picture condition, and which are greater over left and superior parietal sites (see figure 5.12). The pairwise contrast between non-targets and new items revealed an item x hemisphere interaction [$F(1,15) = 13.48$, $p < 0.005$], reflecting old/new effects for non-targets, across condition, that are positive-going over left parietal sites, but negative-going over right parietal sites, although subsidiary analyses indicated that these effects did not reach significance. The contrast between targets and non-targets gave rise to a main effect of item [$F(1,15) = 25.23$, $p < 0.001$], as well as interactions between condition and item [$F(1,15) = 12.34$, $p < 0.005$], between item and site [$F(1.3,20.0) = 11.34$, $p < 0.005$], and between

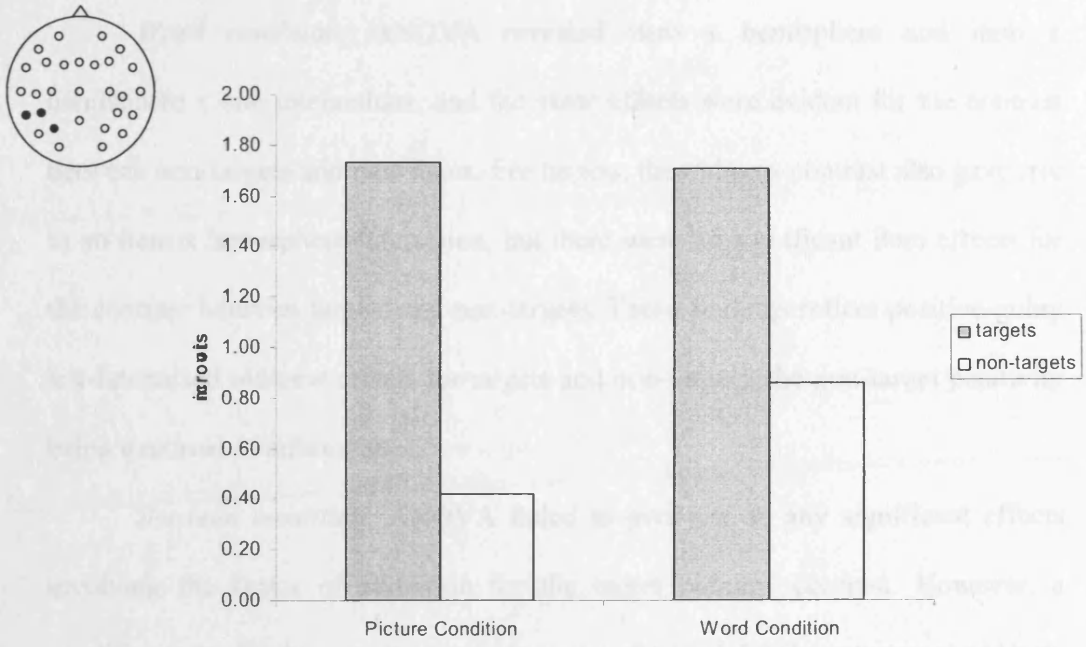

Figure 5.12.
Exp. 2 – Mean amplitudes (μV) of target and non-target old/new effects for the picture condition (left) and the word condition (right) over the 500-800 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

condition, item, hemisphere and site [$F(1.6,24.0) = 4.47$, $p < 0.05$]. Overall, these effects reflect greater positivity for targets, an effect which is larger for targets from the picture condition, and maximal over the left mid-lateral site for the picture condition, but maximal over the right mid-lateral site for the word condition.

900-1100 msec

Picture condition: ANOVA gave rise to a main effect of item and an item x hemisphere interaction. Old/new contrasts gave rise to a main effect of item for targets and an item x hemisphere interaction for both targets and non-targets. The contrast between targets and non-targets revealed a main effect of item and an item x location x site interaction. These findings reflect left-lateralised positive-going old/new effects for both items, and greater positivity for targets compared to non-targets, the latter effect being maximal over superior frontal sites.

Word condition: ANOVA revealed item x hemisphere and item x hemisphere x site interactions, and the same effects were evident for the contrast between non-targets and new items. For targets, the old/new contrast also gave rise to an item x hemisphere interaction, but there were no significant item effects for the contrast between targets and non-targets. These findings reflect positive-going left-lateralised old/new effects for targets and non-targets, the non-target positivity being maximal at inferior sites.

Between condition: ANOVA failed to give rise to any significant effects involving the factor of condition for the target old/new contrast. However, a condition x hemisphere x site interaction was obtained for the non-target old/new contrast [$F(1.5,22.7) = 3.85$, $p < 0.05$], reflecting larger positive-going old/new

effects for non-targets from the word condition, maximal and significant only over left inferior sites.

1100-1400 msec

Picture condition: The initial ANOVA revealed an item x location x site interaction, an effect that was also found for the target old/new contrast, in addition to an item x location interaction. There were no significant effects for pairwise contrasts between non-targets and new items, or between targets and non-targets. These findings reflect old/new effects for targets only, which are generally positive-going and maximal over frontal sites, but negative-going at superior parietal sites.

Word condition: The global analysis gave rise to an item x location interaction and an item x hemisphere x location interaction. Old/new contrasts revealed interactions between item and location, item, hemisphere and location, and item location and site for targets, and between item and hemisphere, and item, hemisphere and location for non-targets. There were no significant effects of item for the contrast between targets and non-targets. These findings indicate old/new effects for both items which are generally positive-going, maximally over right frontal sites for targets and over left temporal sites for non-targets, but negative-going for both items at superior parietal sites.

Between condition: ANOVA failed to give rise to any significant effects involving the factor of condition for the target old/new contrast.

Bilateral frontopolar sites: The focused analysis conducted on data from frontopolar sites for the three item types across condition revealed no significant effects involving the factor of item.

1400-1900 msec

Picture condition: The global analysis gave rise to an item x location x site interaction, an effect that was also found for the target old/new contrast. There were no significant effects for pairwise contrasts between non-targets and new items, or between targets and non-targets. These findings reflect old/new effects for targets only, which are positive-going over most sites, maximal at superior frontal sites, but negative-going at inferior frontal sites and at mid-lateral and superior parietal sites.

Word condition: ANOVA revealed an item x site interaction. There were no significant effects of item for the contrasts between targets and new items. The old/new contrast for non-targets revealed interactions between item and site, between item, hemisphere and location, and between item hemisphere, location and site. The contrast between targets and non-targets gave rise to an item x site interaction. These findings reflect generally negative-going old/new effects for non-targets, significantly over the right hemisphere at superior sites and the mid-lateral parietal site, and significantly greater negativity for non-targets, compared to targets, at mid-lateral sites.

Bilateral frontopolar sites: The *a priori* analysis conducted on data from frontopolar sites for the three item types across condition gave rise to an item x hemisphere interaction [$F(1.4,20.9) = 4.22$, $p < 0.05$]. There were no significant effects involving the factor of item for the contrasts between targets and new items, or between targets and non-targets. The non-target old/new contrast revealed an item x hemisphere interaction [$F(1,15) = 13.58$, $p < 0.005$], reflecting, across

condition, greater negativity for non-targets compared to new items, maximally, but non-significantly, over the left hemisphere.

Topographic analyses

To follow up the results of the magnitude analyses comparing old/new differences across condition, the scalp distribution of non-target old/new effects were contrasted as a function of condition within the 900-1100 msec latency region. The distribution of reliable target and non-target old/new effects were then contrasted within each condition, but only for the latency regions in which the magnitude analyses indicated differences in the distribution of old/new effects across item type. Thus, the distribution of old/new effects were contrasted as a function of item type during the 900-1100 msec latency region for the picture condition and as a function of both item type and latency region (500-800, 900-1100 and 1100-1400 msec) for the word condition. Analyses conducted over the 900-1100 msec latency region, contrasting non-target old/new effects across condition as well as old/new effects across item type within the picture condition, failed to give rise to any condition / item x site interactions. However, ANOVA, contrasting old/new effects across item type and latency region within the word condition, revealed a latency region x site interaction [$F(4.5,67.8) = 3.21$, $p = 0.01$], but no interactions involving item type and site. These findings indicate that, while the scalp distributions of old/new effects in the word condition do not differ according to item type, their topographies do change over time. Figure 5.13 shows that these distributions evolve from a positive centro-left parietal maximum over the 500-800 msec latency region through to positive mid-right frontal and negative central parietal maxima over the 1100-1400 msec latency region.

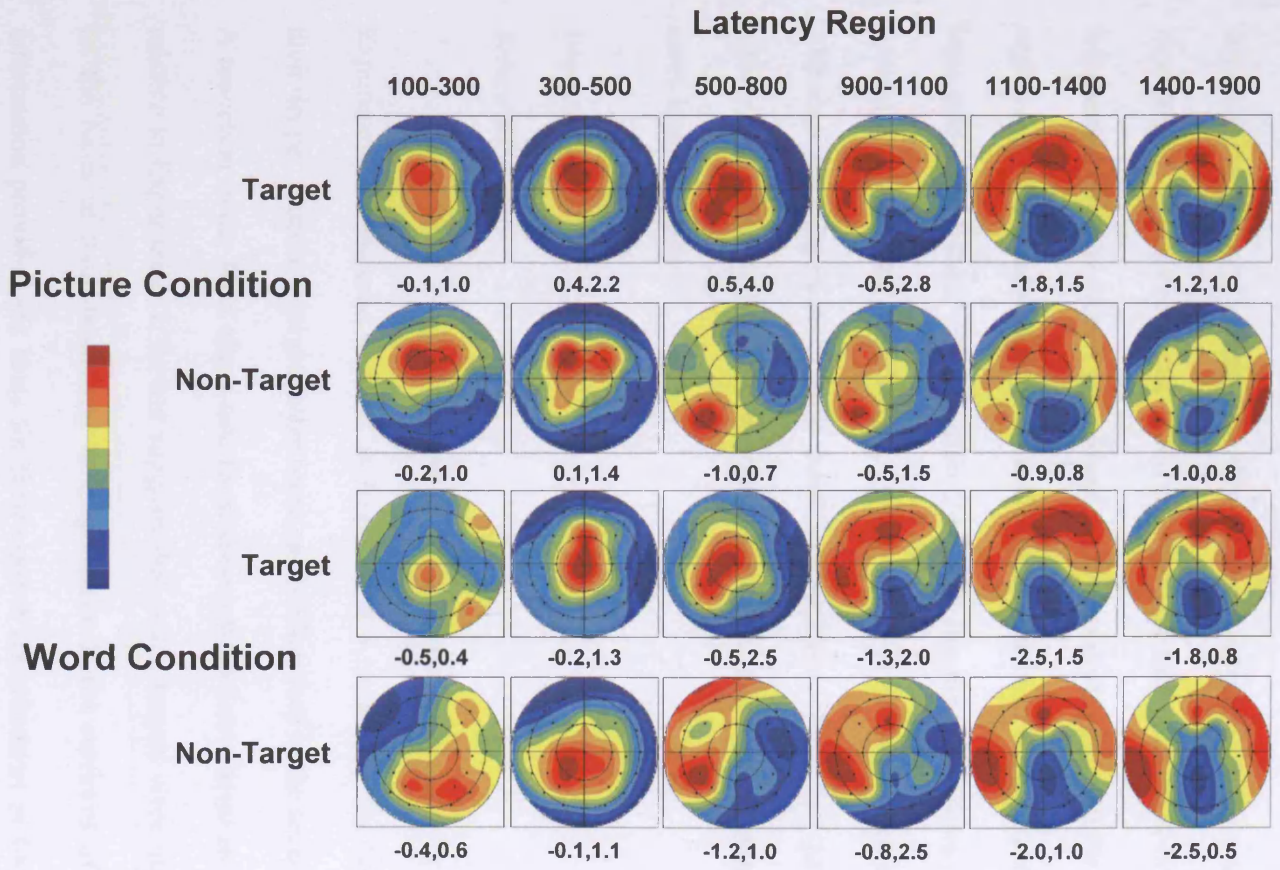

Figure 5.13.
Exp. 2 – Topographic maps of target and non-target old/new effects in the picture condition and the word condition for all latency regions as indicated. The paired values below each map indicate the voltage ranges (microvolts) of the differences between the two types of item (i.e., old-new) and can be interpreted with reference to the bar presented on the far left of the figure.

Summary of results

During the 300-500 msec latency region, targets from the picture condition elicited a reliable early mid-frontal old/new effect, which was only evident for targets from the word condition with a focused analysis over the mid-frontal sites. Non-targets, across condition, failed to elicit this early effect. In both conditions, left parietal old/new effects were found for targets during the 500-800 msec latency region – for the word condition, this effect was shown to differ qualitatively from a later mid-right frontal old/new effect, evident for the same items, and evolving through the 900-1100 msec latency region to the 1100-1400 msec latency region. Although non-targets from both conditions failed to elicit left parietal old/new effects, this effect was evident for non-targets at a later time, during the 900-1100 msec latency region.

Discussion

Behaviour

There were a greater number of accurate responses for all items in Experiment 2 compared to those in Experiment 1, reflecting the fact that, due to their deeper encoding, targets were more easily identified in the second experiment. A reduction in the false alarm rate for non-targets and new items in Experiment 2, relative to Experiment 1, further suggests that, while targets were mainly endorsed on the basis of their familiarity in Experiment 1, the retrieval of target source information provided the basis for their correct classification in Experiment 2. A similar pattern of behaviour to that found in Experiment 1 was found in Experiment 2 – responses were quicker to both targets and non-targets in the picture condition than to those in the word condition. Additionally, for Experiment 2, there was

greater accuracy for non-targets in the picture condition compared to the word condition. These findings suggest that targets and non-targets were more easily and efficiently discriminated in the picture condition. In the word condition only, responses to new items were found to be quicker than those to targets and non-targets. This indicates that the information required for an old/new judgement was available at an earlier time-point than that permitting a source judgement, suggesting that new items were identified on the basis of an absence of familiarity. However, with no significant RT differences between items in the picture condition, as for Experiment 1, it would seem that the information required for the target/non-target discrimination was relatively less specified and more rapidly retrieved in the picture condition than in the word condition.

ERPs

In Experiment 2, correctly recognised targets elicited left parietal old/new effects during the 500-800 msec latency region, suggesting that, in this experiment, these items were identified on the basis of recollection. However, during the same latency region, non-targets did not elicit left parietal old/new effects – as anticipated, it would seem that non-target source was not recollected in this experiment. These findings stand in contrast to those in Experiment 1 where non-targets, but not targets, elicited left parietal old/new effects. These findings concur with those of Herron and Rugg (2003a) who argued that this pattern of ERP effects reflects the adoption of different retrieval strategies according to the availability of target source information. When memory for targets was poor, non-targets elicited a left parietal old/new effect. Given a reduction in the availability of target source information, it would seem that the absence of this information could not provide a

reliable basis to reject non-targets and, therefore, it was necessary to recollect non-target source. However, when memory for targets was good, non-targets failed to elicit a left parietal old/new effect. In this case, as targets could be endorsed on the basis of retrieved information that identified their study source, it was now possible to reject non-targets on the basis of the absence of this information. It would seem, therefore, that a retrieval strategy can be adopted that allows processing resources to be selectively devoted to target recollection. Herron and Rugg (2003b) have proposed that such a strategy reflects the adoption of a specific 'retrieval orientation' which enables test cues to be processed in a way that selectively probes for target recollection. It has previously been shown that the adoption of a retrieval orientation can account for the finding that test words can be used to selectively retrieve episodic information involving target words as opposed to non-target pictures (Herron & Rugg, 2003b). Therefore, the adoption of a retrieval orientation could quite plausibly explain the selective retrieval of target source information in the picture condition in the present experiment. The same mechanism would most parsimoniously account for the same findings in the word condition.

However, the finding of a late left parietal old/new ERP effect during the 900-1100 msec latency region for non-targets when these same items failed to elicit an earlier effect, suggests that the retrieval strategy adopted in Experiment 2 may serve to delay, rather than preclude, the recollection of non-target source. As was argued for similar findings in Experiment 1, it seems unlikely that this effect could reflect processes supporting the recollection of non-target source information as the basis for selecting a response in this experiment. For the picture condition in particular, at a latency of 900 msec post-stimulus, considering mean RT for non-

targets was 1120 msec, motor responses relating to such decisions are likely to have been initiated by this time. Furthermore, if non-targets in both conditions were rejected on the basis of non-target source information (which would, therefore, seem to have been retrieved at approximately the same time-point) it would be hard to account for such a large discrepancy in non-target RTs between the conditions (214 msec). The difference in target and non-target RTs across condition can be more easily accounted for if the proposal that responses were based on the presence / absence of target source information is correct. As left parietal old/new effects were initiated at an earlier time-point for targets, there is a much larger time window within which to accommodate differences in the time required to retrieve sufficient source information for the two conditions. Given their distinct modalities, target and non-target memories in the picture condition should have very few overlapping features compared to those for the same items in the word condition. Given that memory for different types of information have been found to revive at different times (e.g., Johnson *et al.*, 1994), it is possible that information available at the earliest time-point might be sufficient to discriminate between targets and non-targets in the picture condition. If, however, further target source information is required for the same discrimination in the word condition, it is likely that at least some of this information may take more time to revive, accounting for the longer target and non-target RTs in this condition.

In contrast to Experiment 1, ERPs to targets were undifferentiated from those to non-targets and new items until 300 msec post-stimulus. However, in both experiments, between 300-500 msec post-stimulus, an early mid-frontal old/new effect was evident for targets, but not for non-targets, in both conditions. Given that

the early mid-frontal effect is thought to reflect familiarity processing, these findings are surprising as all old items should be familiar, regardless of their target status (Jacoby, 1991). That non-targets were simply forgotten is not a plausible argument for their failure to elicit these early effects as non-targets were apparently recollected as evidenced by left parietal old/new effects for these items, albeit late-onsetting in most cases. Interestingly, a factor in the present experiments, consistent with previous findings of old items failing to elicit early mid-frontal effects, concerns the relatively long retention interval for non-targets compared to that for targets. It is has previously been reported that the early mid-frontal effects can disappear for repeated items when the interval between their first and second presentation exceeds 15 mins (Rugg, 1990). In the present Experiment 2, taking into account the length of time that elapsed between first/last item presentation in each study list and first/last item presentation in the test list, the estimated approximate retention interval for non-targets ranged, on average, between 8½ mins and 25 mins in the picture condition, and between 8½ mins and 31 mins in the word condition. In contrast, the estimated average retention interval for targets ranged between 3½ - 20 mins in the picture condition and 2½ - 19 mins in the word condition.

This difference between targets and non-targets is due to the fact that the non-target study list was always presented prior to the target study list, and is particularly discrepant in the word condition because of the elaborate encoding task (sentence generation) required for non-targets in this condition. Given the above estimates, it would seem likely that, in comparison to targets, a much larger proportion, and possibly over half, of non-targets had a retention interval exceeding

15 mins. Furthermore, this is also likely to be the case for Experiment 1 as the order of study list presentation and the encoding tasks for non-targets remained identical to those in Experiment 2. If relatively long retention intervals lead to the failure of repeated items to elicit early mid-frontal effects when old/new behavioural discriminations remain well above chance (Rugg & Nagy, 1989), this seriously undermines the notion that this ERP effect reflects familiarity-based recognition (Curran & Friedman, 2004).

For both conditions, between 1100-1400 msec, a positive old/new effect with a mid-right frontal maximum was evident for targets. Unlike Experiment 1, the distribution of this effect in Experiment 2 did not extend over the frontopolar sites. However, in both experiments this late frontal effect was not evident for non-targets in either condition. It was argued that the failure of non-targets to elicit this late frontal effect, in Experiment 1, supported the idea that the results of a retrieval attempt associated with vivid recollection should require less monitoring and evaluation than those associated with impoverished recall. However, this argument could not account for the findings in Experiment 2 given that targets and non-targets had both been deeply encoded and were associated with successful recall as reflected by left parietal old/new effects (albeit at a later time-point for non-targets). A similar pattern of findings has previously been reported which led to the notion that the late frontal effect reflects processes that are under strategic control and may vary according to the target status of a retrieved item (Wilding & Rugg, 1997). The pattern of late frontal effects found in the present experiment suggests that monitoring and evaluative operations were carried out only when the presentation of an item led to the retrieval of target source information.

General conclusion

As found previously, the recollection of non-target source information – as indexed by the left parietal old/new effect – is not always necessary to correctly reject these items. When there is good memory for targets, it would seem that the adoption of a specific 'retrieval orientation' allows test cues to selectively probe memory for targets at the expense of non-target recollection. However, the finding of a late left parietal old/new ERP effect for non-targets, when these same items failed to elicit an earlier effect, suggests that the retrieval strategy adopted may serve to delay, rather than preclude, the recollection of non-targets. These findings suggest that complex recognition tasks engage a flexible system that can modulate processes involved in recognition. An outstanding question arising from these findings is why left parietal old/new effects for correctly rejected non-targets have previously been found, despite reports of good target accuracy. It would seem that there are factors, in addition to target saliency, that will influence the use of non-target recollection. One such factor possibly concerns the degree of similarity between target and non-target study contexts. Presumably, the adoption of a retrieval strategy, allowing exclusive recollection of target source, will be more successful when there are fewer overlapping contextual features associated with targets and non-targets engendered during the study phase. This outstanding issue will be investigated at a later point in this thesis.

CHAPTER 6

Investigating the functional significance of the early P2 modulation:

Experiment 3

Introduction

Experiment 3 further investigated findings from Experiment 1 that ERPs to targets were more positive than those to both non-targets and new items at a latency of 100-300 msec post-stimulus. There were no amplitude differences between non-targets and new items in Experiment 1 during the same latency region. Although not usually observed in study-test recognition, more recently, there have been similar reports of early (100-300 msec) old/new effects in recognition tests (e.g., Curran, 1999; Curran & Dien, 2003; Tsivilis *et al.*, 2001). These effects have been found over frontopolar locations for items studied in a visual, as opposed to an auditory, modality (Curran & Dien, 2003), for pseudo-words rather than words (Curran, 1999) and for visual objects and complex scenes when objects were presented against a backdrop of different environmental settings (Tsivilis *et al.*, 2001). It seems that this early modulation is sensitive to within-modality repetition for visually presented items and has been proposed to support recognition memory (Tsivilis *et al.*, 2001). However, it is far from certain what the functional significance of this early modulation might be. Interestingly, outside of the memory domain, modulations of an anterior P2 have been reported for task-relevant stimuli (Potts, 2004) and have been associated with mechanisms of selective attention (e.g., Hackley, Woldorff & Hillyard, 1990) as well as feature

detection (Luck & Hillyard, 1994). The P2 modulation within the context of recognition tasks might, therefore, reflect the engagement of attentional processes for task-relevant perceptual information, and may well be affected by rehearsal strategies used during encoding and/or the choice of strategy used at retrieval.

In Experiment 1 reported in this thesis, this early target old/new effect did not vary as a function of condition where, at study, pictures were used as non-target stimuli for one condition and words were used as non-target stimuli for the other condition. This suggests that targets were discriminated from non-targets in both conditions at less than 200 msec post-stimulus. However, this effect does not seem to have been sufficient to allow an overt behavioural response discriminating targets and non-targets as RTs for these items would, otherwise, not have differed between picture and word conditions. Findings from Experiments 1 and 2 indicate that this early P2 modulation was observed for shallowly-encoded words as opposed to deeply-encoded words and pictures (Experiment 1) – when targets were also deeply encoded (Experiment 2), this early effect disappeared. The present experiment aims to replicate this previous finding of an early old/new effect for shallowly-encoded target words but not for deeply-encoded non-target words. Experiment 3 employed a hybrid of the experimental designs used previously, taking the blocks from Experiments 1 and 2 corresponding to the word condition to be employed, in the present experiment, in a within-subject design. Accordingly, in the 'shallow' condition, targets were shallowly encoded and, in the 'deep' condition, targets were deeply encoded – in both conditions non-targets were deeply encoded. This design represented a replication of that employed by Herron and Rugg (2003a) but with target encoding manipulated within- rather than

between-subjects. In this way, the hypothesis that it is the shallow-encoding of target items, in contrast to the deep-encoding of non-target items, giving rise to this early P2 modulation will be directly tested.

Method

Participants

Twenty three students participated in this experiment. Data from 5 of these participants were discarded due to the failure to provide 16 or more artefact-free trials for one or more of the critical conditions. Of the remaining 18 participants, 10 were male and 8 were female, and their ages ranged between 19-35 years (mean age: 23 years).

Stimuli, design and procedures

A 2 (condition: shallow; deep) x 3 (item: targets; non-targets; new items) within-subject design was employed in this experiment, and consisted of 2 blocks, each comprising three phases; study list 1, study list 2 and test. Figure 6.1 illustrates the design for Experiment 3. The stimulus set, methods and procedures were almost identical to those employed in Experiments 1 and 2, except the stimuli were presented as words only. Each participant completed two study-study-test blocks, one block corresponding to the shallow condition and the other corresponding to the deep condition. For the non-target study phase, in each condition, participants were required to incorporate each presented word into a self-constructed sentence and to verbally repeat this sentence aloud. For the target study phase, participants were required to perform one of two tasks depending

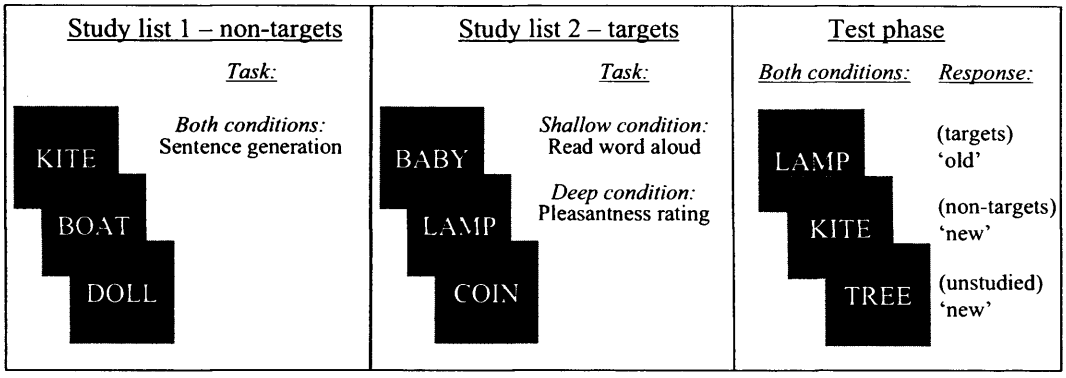

Figure 6.1.
Exp. 3 – design. Study-study-test blocks depicting study tasks in each condition, with examples of study/test items and their correct responses at test.

upon the condition. For the shallow condition, participants were required to merely repeat each word aloud. For the deep condition, participants were required to verbally rate each word for pleasantness on a scale from 1 (unpleasant) to 5 (pleasant). Instructions for the test phase of each condition were identical to those given in Experiments 1 and 2. EEG and EOG recording parameters, trial rejection criteria and blink correction procedures were also identical to those employed in Experiments 1 and 2.

Results

Behavioural data

Table 6.1 shows the mean percent accuracy and RTs for correctly classified target, non-target and new items for each condition. A 2 (condition: shallow, deep) x 3 (item: target, non-target, new) repeated measures ANOVA of the accuracy data revealed a main effect of condition [$F(1,17) = 29.30$, $P < 0.001$], a main effect of item [$F(2,34) = 108.64$, $p < 0.001$] and a condition x item interaction [$F(1.4,24.5) = 22.53$, $p < 0.001$]. Bonferroni t-tests (adjusted alpha level: 0.017) revealed that,

Table 6.1.
Exp. 3 – Mean percent accuracy and reaction time (including standard deviations) for correctly classified targets, non-targets and new items as a function of condition.

CONDITION	ITEM TYPE	% CORRECT	RT (SD)
Shallow	Targets	60 (9)	1382 (175)
	Non-targets	88 (6)	1343 (200)
	New	92 (9)	1183 (220)
Deep	Targets	82 (13)	1279 (198)
	Non-targets	89 (6)	1325 (196)
	New	97 (4)	1147 (221)

while non-target accuracy did not differ between condition, responses to targets and new items from the deep condition were more accurate than those to the same items from the shallow condition [targets: $t(17) = 6.33$, $p < 0.001$; new items: $t(17) = 2.67$, $p < 0.05$)]. ANOVA performed on the RT data gave rise to a main effect of condition [$F(1,17) = 7.40$, $p < 0.05$], indicating increased RTs, overall, for items from the shallow condition. There was also a main effect of item [$F(2,34) = 20.65$, $p < 0.001$] – comparison of RTs between items collapsed across condition revealed that, while there was no difference in RTs between targets and non-targets, new items were responded to more quickly than both targets [$F(1,35) = 42.96$, $p < 0.001$] and non-targets [$F(1,35) = 57.10$, $p < 0.001$].

ERP data

The mean number (and range) of trials contributing to ERPs to target, non-target and new items were 27 (16-41), 41 (26-54) and 43 (26-55) respectively for the shallow condition and 39 (22-56), 41 (26-52) and 44 (29-56) respectively for

the deep condition. Grand average waveforms associated with the three item types for the shallow and deep conditions are shown for selected electrode sites in figures 6.2 and 6.3, respectively.

From around 100 msec post-stimulus, ERPs to targets from the shallow condition briefly show only slightly greater positivity than ERPs to non-targets and new items at superior frontal and right inferior / temporal sites. ERPs from the shallow condition diverge to a much greater extent between 300-500 msec when both targets and non-targets can be seen to elicit greater positivity in comparison to new items, particularly over left frontal sites. During the same latency region, a small positive old/new effect over superior frontal sites is also apparent for targets from the deep condition. From around 400 msec post-stimulus, target ERPs from both conditions show a small enhanced positivity compared to new item ERPs over left parietal sites, although this effect is quite short-lived, lasting for approximately 200-300 msec. There is a much larger, and more sustained, left parietal old/new effect for non-targets from the shallow condition, although this is confined to left inferior / mid-lateral parietal sites. ERPs to non-targets from the deep condition are undifferentiated from those to new items until around 500 msec post-stimulus when there is a large and sustained negative-going old/new effect for these items over most right hemisphere sites as well as at left mid-lateral / superior frontal sites. While this negative-going old/new effect can be seen for all items from around 600 or 700 msec post-stimulus (maximally over the right superior parietal site) this is more topographically widespread for non-targets from the deep condition. A late-onsetting (around 900-1100 msec post-stimulus) left parietal old/new effect is apparent for non-targets from both conditions, although this is small and confined

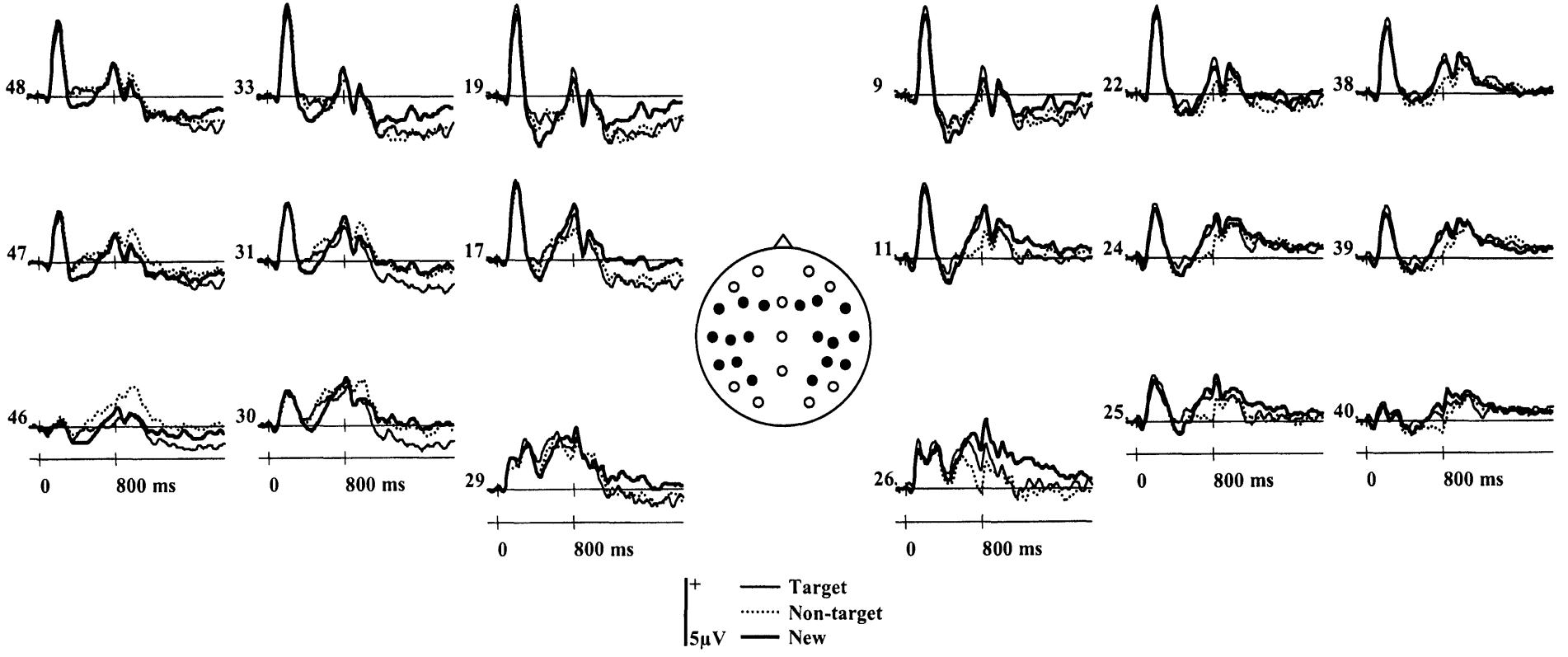

Figure 6.2.
Exp. 3 – Shallow condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontal (48, 33, 19, 38, 22, 9), lateral temporal (47, 31, 17, 29, 24, 11) and lateral parietal sites (46, 30, 29, 40, 25, 26).

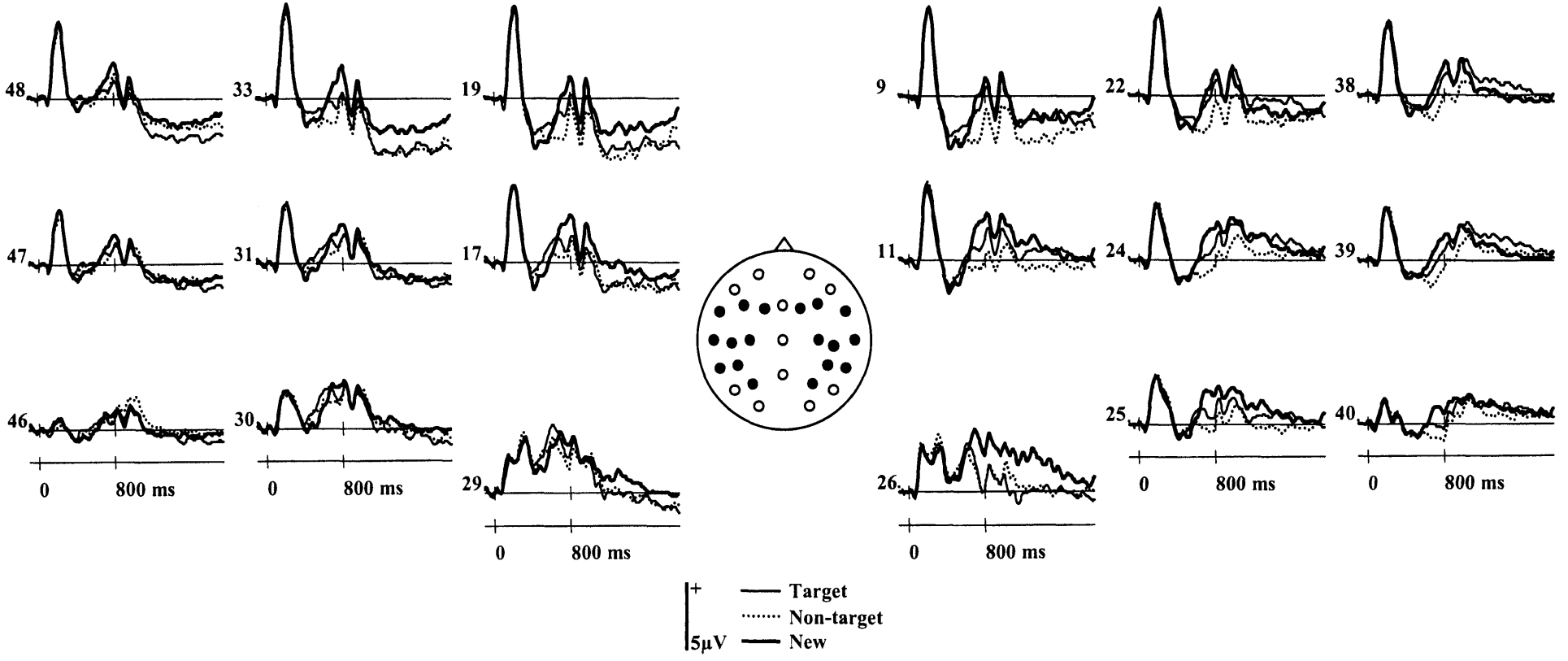

Figure 6.3.
Exp. 3 – Deep condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at electrode sites as described in Figure 6.2.

to the left inferior parietal site for non-targets from the deep condition.

Global analyses were initially performed on data from targets, non-targets and new items, for each condition separately, at the same lateral frontal, temporal and parietal sites as chosen for Experiments 1 and 2 (and as described in Chapter 4). These analyses were conducted within six latency regions (100-300 msec; 300-500 msec; 500-800 msec; 900-1100 msec; 1100-1400 msec; 1400-1900 msec) and employed the factors of item, hemisphere, location and site. The results of these analyses are shown in tables 6.2 and 6.3 for the shallow condition and deep condition respectively. However, results for the 100-300 msec latency region for both conditions, as well as for the 300-500 msec latency region for the deep condition, are omitted from these tables as the initial ANOVAs for the respective latency regions / conditions failed to give rise to significant effects of item. In order to demonstrate any differences between target and non-target old/new effects according to whether targets were shallowly or deeply encoded, a second set of global analyses compared reliable target and non-target old/new effects across condition. This second set of global ANOVAs employed the factors of condition, hemisphere, location and site. A third set of global analyses compared correctly rejected new items across condition, employing the factors of condition, hemisphere, location and site. For this latter set of analyses, only those revealing significant effects involving the factor of condition will be reported. *A priori* analyses were conducted on data from mid-frontal sites within the 300-500 msec latency region, from lateral parietal sites within the 500-800 msec latency region and from lateral frontopolar sites during the 1100-1400 msec and 1400-1900 msec latency regions. An additional analysis was conducted on data from left parietal

Table 6.2.
Exp. 3 – Summary of ANOVA results in each ERP latency region for the shallow condition.

	300-500 msec	500-800 msec	900-1100 msec	1100-1400 msec	1400-1900 msec
Targets/non-targets/new					
IT x HM	$F_{1.8,30.6} = 8.13$, $p < 0.005$	$F_{1.8,29.9} = 8.33$, $p < 0.005$	$F_{1.6,26.4} = 7.39$, $p = 0.005$	–	–
IT x ST	–	–	$F_{1.7,29.3} = 3.58$, $p < 0.05$	$F_{1.7,28.7} = 9.43$, $p = 0.001$	$F_{1.8,30.3} = 7.56$, $p < 0.005$
IT x HM x AP	$F_{2.9,50.0} = 6.17$, $p = 0.001$	$F_{3.0,50.5} = 4.29$, $p < 0.01$	–	$F_{2.6,44.1} = 3.27$, $p < 0.05$	–
IT x HM x ST	–	$F_{2.7,46.2} = 5.73$, $p < 0.005$	$F_{2.0,34.6} = 5.70$, $p < 0.01$	–	–
IT x AP x ST	–	–	$F_{4.1,69.9} = 4.38$, $p < 0.005$	$F_{4.1,69.7} = 4.04$, $p = 0.005$	$F_{3.9,66.3} = 2.48$, $p < 0.05$
Targets/new					
IT	$F_{1,17} = 7.72$, $p = 0.01$	–	–	–	–
IT x ST	–	–	–	$F_{1.1,18.5} = 6.65$, $p < 0.05$	$F_{1.2,19.9} = 5.00$, $p < 0.05$
IT x HM x AP x ST	–	$F_{3.1,53.3} = 2.75$, $p = 0.05$	$F_{2.7,45.9} = 3.04$, $p < 0.05$	–	–
Non-targets/new					
IT x HM	$F_{1,17} = 8.65$, $p < 0.01$	$F_{1,17} = 10.96$, $p < 0.005$	$F_{1,17} = 8.07$, $p = 0.01$	–	–
IT x ST	–	–	$F_{1.1,18.5} = 6.07$, $p < 0.05$	$F_{1.1,19.4} = 17.23$, $p < 0.001$	$F_{1.2,21.0} = 25.21$, $p < 0.001$
IT x HM x AP	–	$F_{1.5,25.3} = 6.00$, $p = 0.01$	$F_{1.7,28.4} = 10.45$, $p = 0.001$	$F_{1.5,25.5} = 10.52$, $p = 0.001$	$F_{1.6,27.4} = 7.57$, $p < 0.005$
IT x HM x ST	$F_{1.6,26.6} = 9.59$, $p < 0.005$	$F_{1.5,25.9} = 7.82$, $p < 0.005$	$F_{1.5,25.1} = 9.18$, $p < 0.005$	–	–
IT x AP x ST	–	$F_{1.7,29.4} = 11.12$, $p < 0.001$	$F_{2.2,37.9} = 7.66$, $p = 0.001$	$F_{2.3,38.6} = 6.23$, $p < 0.005$	–
IT x HM x AP x ST	–	–	$F_{2.7,45.7} = 3.28$, $p < 0.05$	–	–
Targets/non-targets					
IT x HM	–	$F_{1,17} = 10.01$, $p < 0.005$	$F_{1,17} = 13.57$, $p < 0.005$	–	–
IT x HM x AP	–	$F_{2.0,33.3} = 7.09$, $p < 0.005$	–	–	$F_{1.4,23.9} = 3.70$, $p = 0.05$
IT x HM x ST	$F_{1.5,26.0} = 5.12$, $p < 0.05$	$F_{1.5,25.3} = 12.61$, $p < 0.001$	$F_{1.2,21.1} = 11.23$, $p < 0.005$	–	–
IT x AP x ST	–	$F_{2.2,36.8} = 7.90$, $p = 0.001$	–	$F_{2.5,43.2} = 5.11$, $p < 0.01$	$F_{2.4,41.2} = 3.51$, $p < 0.05$

IT = item type; HM = hemisphere; AP = location; ST = site.

Table 6.3.
Exp. 3 – Summary of ANOVA results in each ERP latency region for the deep condition.

	500- 800 msec	900-1100 msec	1100-1400 msec	1400-1900 msec
Targets/non-targets/new				
IT	$F_{1.9,33.1} = 3.29$, $p = 0.05$	–	–	–
IT x HM	–	$F_{2.0,33.5} = 6.69$, $p < 0.005$	$F_{1.7,28.9} = 4.87$, $p < 0.05$	$F_{1.6,27.6} = 4.06$, $p < 0.05$
IT x ST	–	$F_{1.5,24.7} = 4.49$, $p < 0.05$	$F_{1.9,32.4} = 10.16$, $p < 0.001$	$F_{1.9,33.1} = 6.10$, $p < 0.01$
IT x HM x AP	$F_{2.7,45.7} = 4.35$, $p = 0.01$	$F_{2.3,38.7} = 5.44$, $p < 0.01$	$F_{2.3,39.4} = 6.47$, $p < 0.005$	$F_{2.9,49.4} = 4.73$, $p < 0.01$
IT x HM x ST	–	$F_{1.9,32.7} = 3.60$, $p < 0.05$	–	–
IT x AP x ST	–	–	$F_{3.5,59.3} = 3.55$, $p < 0.05$	–
IT x HM x AP x ST	–	$F_{4.1,69.6} = 3.36$, $p = 0.01$	$F_{4.1,69.6} = 2.46$, $p = 0.05$	–
Targets/new				
IT x HM	–	–	–	$F_{1,17} = 4.68$, $p < 0.05$
IT x ST	–	$F_{1.1,18.5} = 4.43$, $p < 0.05$	$F_{1.2,20.2} = 9.19$, $p = 0.005$	–
IT x HM x AP	$F_{1.7,28.8} = 5.48$, $p = 0.01$	$F_{1.6,26.4} = 8.60$, $p < 0.005$	$F_{1.6,26.5} = 9.45$, $p < 0.005$	$F_{2.0,33.2} = 6.47$, $p < 0.005$
IT x AP x ST	–	–	$F_{2.3,39.4} = 5.23$, $p < 0.01$	–
IT x HM x AP x ST	$F_{2.2,37.6} = 3.14$, $p = 0.05$	$F_{2.4,40.0} = 5.35$, $p < 0.01$	$F_{2.5,43.0} = 3.47$, $p < 0.05$	–
Non-targets/new				
IT	$F_{1,17} = 5.38$, $p < 0.05$	–	–	–
IT x HM	$F_{1,17} = 6.57$, $p < 0.05$	$F_{1,17} = 8.86$, $p < 0.01$	–	–
IT x ST	–	$F_{1.1,18.6} = 5.36$, $p < 0.05$	$F_{1.2,21.0} = 15.90$, $p < 0.001$	$F_{1.1,19.4} = 9.60$, $p = 0.005$
IT x HM x AP	$F_{1.5,24.9} = 5.36$, $p < 0.05$	$F_{1.4,23.3} = 7.02$, $p < 0.01$	$F_{1.3,22.4} = 10.93$, $p < 0.005$	$F_{1.3,22.5} = 9.95$, $p < 0.005$
Targets/non-targets				
IT x HM	–	$F_{1,17} = 12.32$, $p < 0.005$	$F_{1,17} = 14.46$, $p = 0.001$	$F_{1,17} = 5.47$, $p < 0.05$
IT x AP	–	$F_{1.3,21.7} = 4.13$, $p < 0.05$	–	–
IT x HM x ST	–	$F_{1.3,21.8} = 6.43$, $p = 0.01$	$F_{1.4,23.5} = 4.37$, $p < 0.05$	–
IT x AP x ST	$F_{1.8,30.9} = 3.70$, $p < 0.05$	–	$F_{1.9,32.6} = 4.15$, $p < 0.05$	–

IT = item type; HM = hemisphere; AP = location; ST = site.

sites between 500-650 msec in order to investigate the small positivity that can be seen for targets at left parietal sites during this latency region. These focused analyses employed the factors of condition and item, as well as hemisphere and / or site. When appropriate, topographic analyses were also conducted to determine whether reliable target and non-target old/new effects differed qualitatively, both within and across condition, as well as across different latency regions.

Magnitude analyses

100-300 msec

The global analysis of new items across condition gave rise to a significant condition x location x site interaction [$F(2.8,47.7) = 3.21$, $p < 0.05$], reflecting greater positivity for new items from the deep condition, significant at inferior parietal and inferior temporal sites. ANOVAs performed on data from items for each condition separately failed to give rise to any significant effects involving the factor of item for the shallow condition or for the deep condition.

300-500 msec

Shallow condition: ANOVA gave rise to an item x hemisphere interaction, as well as an item x hemisphere x location interaction. Old/new contrasts gave rise to a main effect of item for targets, and, for non-targets, interactions between item and hemisphere, as well as between item, hemisphere and site. For the contrast between targets and non-targets, an item x hemisphere x site interaction was found. These findings reflect a widely distributed positive-going old/new effect for targets, and a positive old/new effect for non-targets over the left hemisphere, maximal at inferior sites, but a negative old/new effect for the same items over the right

hemisphere at mid-lateral and inferior sites. While ERPs to targets were more positive than those to non-targets over right hemisphere sites and left superior sites, subsidiary analysis revealed that these differences between targets and non-targets did not reach significance.

Deep condition: The global analysis failed to give rise to any significant effects involving the factor of item.

Mid-frontal sites: The focused analysis conducted on data from mid-frontal sites for the three item types across condition failed to gave rise to any effects involving the factor of item. Figure 6.4 shows the mean amplitudes of target and non-target old/new effects for both conditions for this latency region collapsed across the three mid-frontal sites.

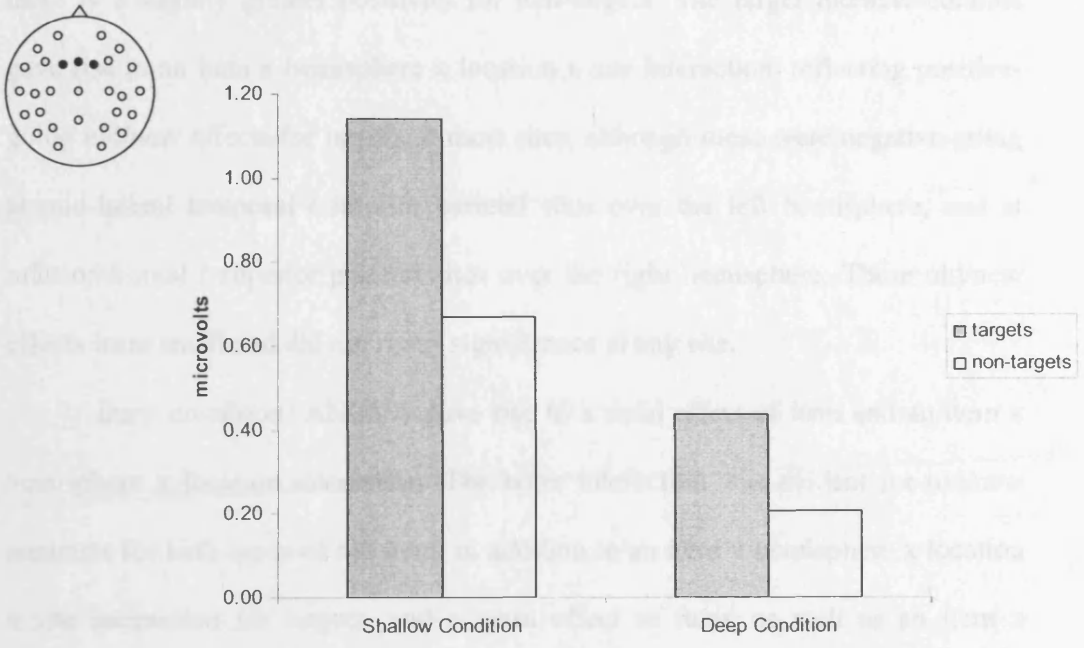

Figure 6.4.
Exp. 3 – Mean amplitudes (μV) of target and non-target old/new effects for the shallow condition (left) and the deep condition (right) over the 300-500 msec latency region. The mean amplitudes are collapsed across the three mid-frontal sites as indicated.

500-800 msec

Shallow condition: The global analysis revealed a number of significant item effects, including interactions with hemisphere, with hemisphere and location, and with hemisphere and site. The same pattern of effects, in addition to an item x location x site interaction, were found for the contrasts between non-targets and new items, as well as between targets and non-targets. These findings reflect greater positivity for non-targets, in comparison to both targets and new items, over most left hemisphere sites, maximal at left parietal / inferior sites, but greater positivity for targets and new items, compared to non-targets, over right hemisphere sites, maximal at right parietal / superior sites. Also, bilaterally, there is greater positivity for targets and new items, compared to non-targets, at most sites / locations, maximally at superior parietal sites, except at inferior parietal sites where there is a slightly greater positivity for non-targets. The target old/new contrast gave rise to an item x hemisphere x location x site interaction, reflecting positive-going old/new effects for targets at most sites, although these were negative-going at mid-lateral temporal / inferior parietal sites over the left hemisphere, and at inferior frontal / superior parietal sites over the right hemisphere. These old/new effects were small and did not reach significance at any site.

Deep condition: ANOVA gave rise to a main effect of item and an item x hemisphere x location interaction. The latter interaction was evident for old/new contrasts for both types of old item, in addition to an item x hemisphere x location x site interaction for targets, and a main effect of item, as well as an item x hemisphere interaction for non-targets. An item x location x site interaction was evident for the contrast between targets and non-targets. For targets, these findings

reflect old/new effects which are negative at most sites, maximal at the right superior parietal site, but positive at left parietal, left mid-lateral temporal and right superior frontal sites, although none of these effects were reliable at any site. However, there was greater positivity for targets compared to non-targets, maximal and significant at superior frontal sites. For non-targets, these findings reflect negative old/new effects, maximal at frontal sites over the left hemisphere and at temporal sites over the right hemisphere.

Between condition: ANOVA, contrasting non-target old/new effects across condition, revealed a main effect of condition [$F(1,17) = 5.11$, $p < 0.05$] and a condition x location x site interaction [$F(3.0,51.2) = 9.85$, $p < 0.001$], indicating, overall, greater negative old/new effects for non-targets from the deep condition, and that, while these negative old/new effects are maximal at superior parietal sites for non-targets from the shallow condition, these are maximal at superior frontal sites for non-targets from the deep condition.

Bilateral parietal sites: The *a priori* analysis conducted on data from all three item types across condition over lateral parietal sites gave rise to an item x hemisphere interaction [$F(2.0,33.2) = 9.81$, $p < 0.001$], a condition x item x hemisphere interaction [$F(1.8,29.8) = 4.48$, $p < 0.05$] and an item x hemisphere x site interaction [$F(3.1,51.9) = 7.11$, $p < 0.001$]. The contrast between targets and new items revealed interactions between condition, item and hemisphere, and between item, hemisphere and site. Subsidiary analysis found an interaction between item, hemisphere and site for the shallow condition, reflecting greater positivity for targets at mid-lateral and left superior parietal sites, but greater positivity for new items at inferior and right superior parietal sites. For the deep

condition, subsidiary analysis revealed an item x hemisphere interaction, reflecting target old/new effects which are positive over left parietal sites but negative over right parietal sites. Simple effects, however, revealed that, for both conditions, these target old/new effects were not reliable. The contrast between non-targets and new items gave rise to an item x hemisphere interaction [$F(1,17) = 16.94$, $p = 0.001$], reflecting, across condition, old/new effects that were positive over left parietal sites, but negative over right parietal sites. While this non-target negativity was significant at right parietal sites, subsidiary analysis at left parietal sites gave rise to a condition x item x site interaction [$F(1.3,22.0) = 4.30$, $p < 0.05$], reflecting positive-going old/new effects for non-targets from the shallow condition only, significant at the left inferior parietal site [$F(1,17) = 13.49$, $p = 0.001$] (see figure 6.5). The contrast between targets and non-targets gave rise to a number of item

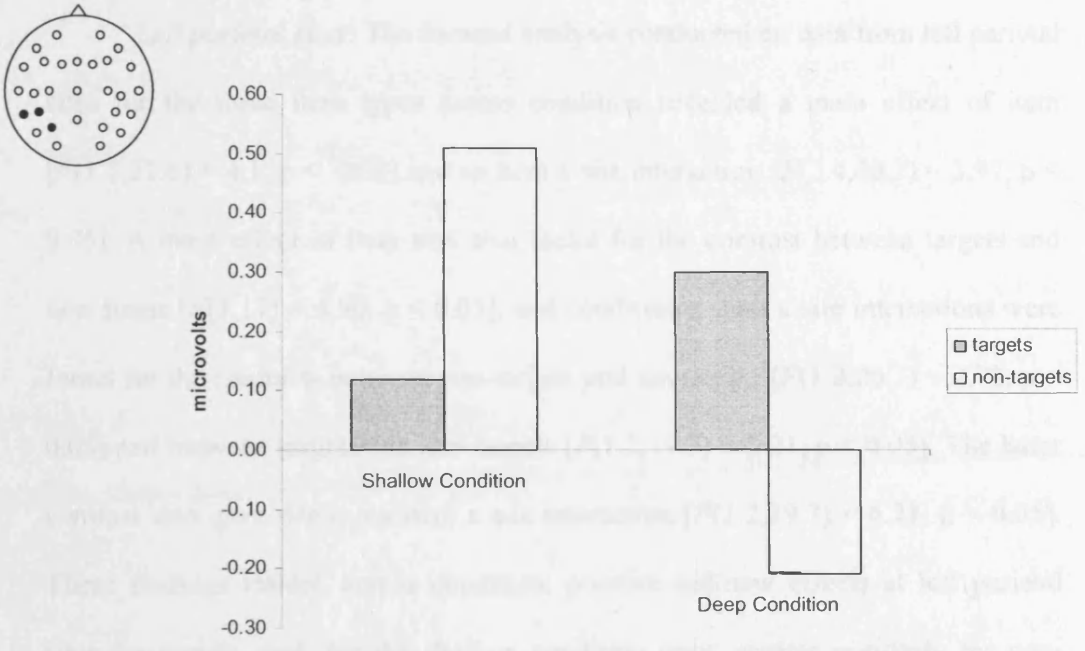

Figure 6.5.
Exp. 3 – Mean amplitudes (μV) of target and non-target old/new effects for the shallow condition (left) and the deep condition (right) over the 500-800 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

effects, including interactions with hemisphere [$F(1,17) = 7.14$, $p < 0.05$], with site [$F(1.3,21.4) = 6.87$, $p = 0.01$], and with hemisphere and site [$F(1.7,28.4) = 12.97$, $p < 0.001$], as well as a condition x item x hemisphere interaction [$F(1,17) = 7.19$, $p < 0.01$]. Subsidiary analyses revealed item x hemisphere x site interactions for both conditions [shallow: $F(1.5,25.8) = 11.59$, $p = 0.001$; deep: $F(1.6,26.8) = 4.58$, $p < 0.05$], and an item x hemisphere interaction for the shallow condition only [$F(1,17) = 14.69$, $p = 0.001$]. For the shallow condition, these findings reflect greater positivity for non-targets at left mid-lateral / inferior parietal sites, but greater positivity for targets at left superior and right parietal sites. For the deep condition, these findings reflect greater positivity for targets at all parietal sites, maximally, but non-significantly, at the right mid-lateral parietal site.

500-650 msec

Left parietal sites: The focused analysis conducted on data from left parietal sites for the three item types across condition revealed a main effect of item [$F(1.3,21.6) = 4.1$, $p < 0.05$] and an item x site interaction [$F(2.4,40.2) = 3.97$, $p < 0.05$]. A main effect of item was also found for the contrast between targets and new items [$F(1,17) = 4.90$, $p < 0.05$], and condition x item x site interactions were found for the contrasts between non-targets and new items [$F(1.2,20.3) = 4.72$, $p < 0.05$] and between targets and non-targets [$F(1.2,19.7) = 6.21$, $p < 0.05$]. The latter contrast also gave rise to an item x site interaction [$F(1.2,19.7) = 6.21$, $p < 0.05$]. These findings reflect, across condition, positive old/new effects at left parietal sites for targets, and, for the shallow condition only, greater positivity for non-targets compared to both targets and new items, maximal at left inferior parietal sites (see figure 6.6).

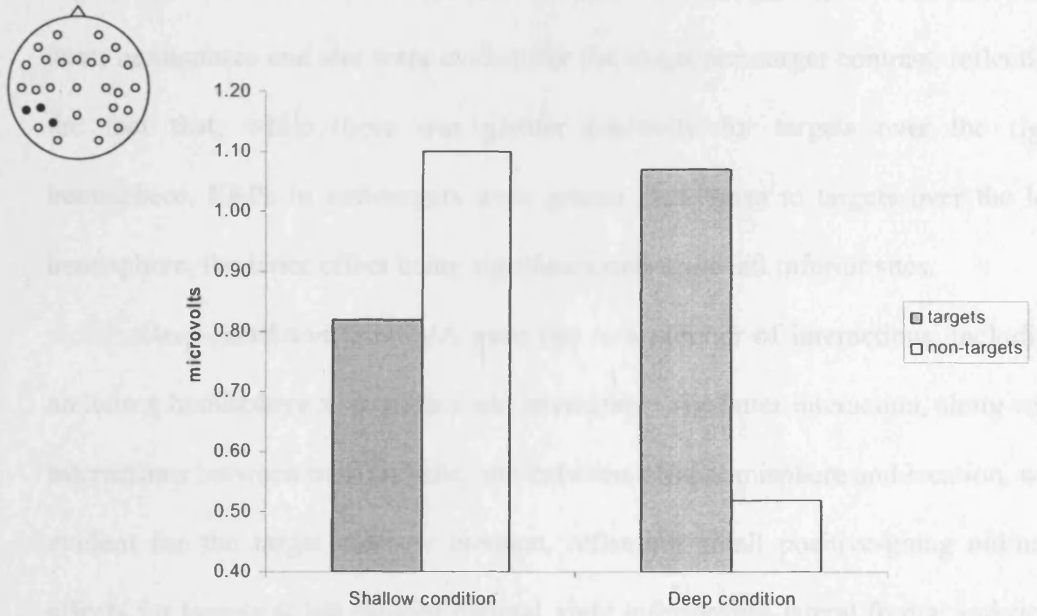

Figure 6.6.
Exp. 3 – Mean amplitudes (μV) of target and non-target old/new effects for the shallow condition (left) and the deep condition (right) over the 500-650 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

900-1100 msec

Shallow condition: The global analysis revealed a number of item effects including interactions with hemisphere, with site, with hemisphere and site, and with location and site. The contrast between targets and new items gave rise to an item x hemisphere x location x site interaction, reflecting mainly negative-going old/new effects for targets, except over right frontal sites where there is a small positivity for the same items, maximal and significant at the right superior parietal site. The non-target old/new contrast gave rise to a number of interactions including an item x hemisphere x location x site interaction. These findings reflect positive-going old/new effects for non-targets at left inferior, left parietal and left mid-lateral temporal sites, maximal at the left inferior parietal site, but negative-going old/new effects for the same items at all other sites, maximal at the right

superior parietal site. Interactions between item and hemisphere, as well as between item, hemisphere and site were evident for the target/non-target contrast, reflecting the fact that, while there was greater positivity for targets over the right hemisphere, ERPs to non-targets were greater than those to targets over the left hemisphere, the latter effect being significant only over left inferior sites.

Deep condition: ANOVA gave rise to a number of interactions, including an item x hemisphere x location x site interaction. The latter interaction, along with interactions between item and site, and between item, hemisphere and location, was evident for the target old/new contrast, reflecting small positive-going old/new effects for targets at left inferior parietal, right inferior/mid-lateral frontal and right inferior temporal sites, but negative-going old/new effects for the same items over all other sites, maximally at the right superior parietal site. The non-target old/new contrast revealed interactions between item and hemisphere, item and site, and between item, hemisphere and location, reflecting mainly negative-going old/new effects for non-targets, maximal at superior sites, except at left parietal sites where there is a small positivity for the same items. For the target/non-target contrast, interactions between item and hemisphere, item and location, and between item, hemisphere and site were found, reflecting, bilaterally, more positivity for targets over frontal and temporal locations, but more positivity for non-targets over parietal locations. Also, while ERPs to non-targets were more positive than those to targets at left inferior / mid-lateral sites, there was greater positivity for targets at left / right superior and right inferior sites, as well as at right mid-lateral sites where this effect was maximal.

Between condition: ANOVA for the target old/new contrast across condition gave rise to a condition x hemisphere x location interaction [F(1.7,29.0) = 4.37, p 0.05], reflecting greater negative old/new effects for targets from the deep condition compared to those from the shallow condition, maximally, over left frontal locations. Analysis for the non-target old/new contrast across condition revealed a condition x location x site interaction [F(2.8,47.0) = 5.21, $p < 0.005$], reflecting greater negative old/new effects for non-targets from the deep condition in comparison to those from the shallow condition, maximally, over superior frontal sites.

1100-1400 msec

Shallow condition: The global analysis revealed interactions between item and site, between item, hemisphere and location, and between item, location and site. The same pattern of effects was also found for the non-target old/new contrast, an item x site interaction was revealed for the target old/new contrast, and an item x location x site interaction was evident for the target/non-target contrast. These findings reflect negative-going old/new effects for targets, maximally, but non-significantly, at superior sites, and negative-going old/new effects for non-targets, maximal and significant at right and superior parietal sites, except over bilateral inferior sites where there are small positive-going old/new effects for the same items. Findings for the target/non-target contrast reflect greater positivity for targets over frontal and superior parietal sites, but greater positivity for non-targets at all other sites, maximal at inferior parietal sites.

Deep condition: ANOVA revealed a number of interactions, including an item x hemisphere x location x site interaction. A similar pattern of effects was

found for the target old/new contrast, reflecting negative-going old/new effects for targets over all left hemisphere sites and most right hemisphere sites, maximal at the right superior parietal site, but (non-significant) positive-going old/new effects for the same items at right inferior frontal / temporal and right mid-lateral frontal sites. The non-target old/new contrast revealed interactions between item and site, as well as between item, hemisphere and location, reflecting negative-going old/new effects for non-targets, maximal at bilateral superior and right parietal sites. For the target/non-target contrast there were a number of item effects, including interactions with hemisphere, with hemisphere and site, and with location and site, reflecting greater negativity for non-targets over most sites, maximal at right mid-lateral sites, but greater negativity for targets at left inferior/mid-lateral and inferior/superior parietal sites.

Between condition: ANOVA contrasting non-target old/new effects across condition gave rise to a condition x location x site interaction [$F(3.3,55.5) = 3.25$, $p < 0.05$], reflecting mainly negative-going old/new effects for non-targets, effects which are maximal at superior parietal sites for the shallow condition, but maximal at superior frontal sites for the deep condition.

Bilateral frontopolar sites: Grand average waveforms from frontopolar sites are shown in figures 6.7 and 6.8 for the shallow and deep conditions respectively. The *a priori* analysis conducted on data from frontopolar sites for the three item types across condition revealed a main effect of condition [$F(1,15) = 13.80$, $p < 0.005$], along with interactions between item and hemisphere [$F(1.9,28.8) = 3.88$, $p < 0.05$], between condition, item and hemisphere[$F(1.8,26.9) = 5.22$, $p < 0.05$] and between condition, item, hemisphere and site [$F(1.7,26.2) =$

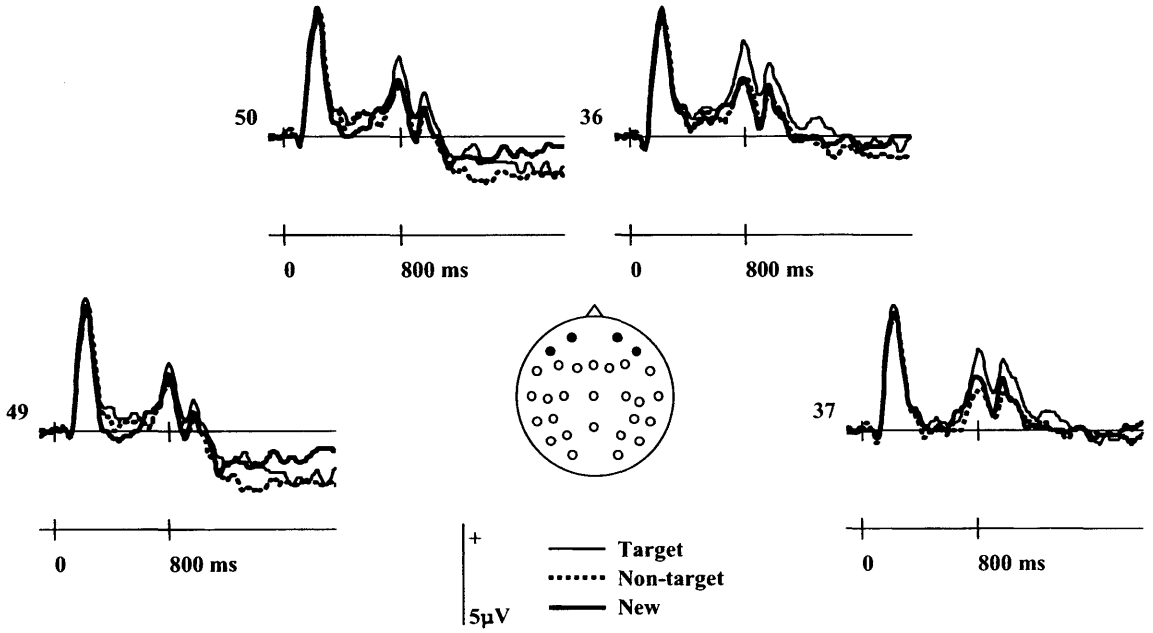

Figure 6.7.
Exp. 3 – Shallow condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontopolar sites (49, 50, 37, 36).

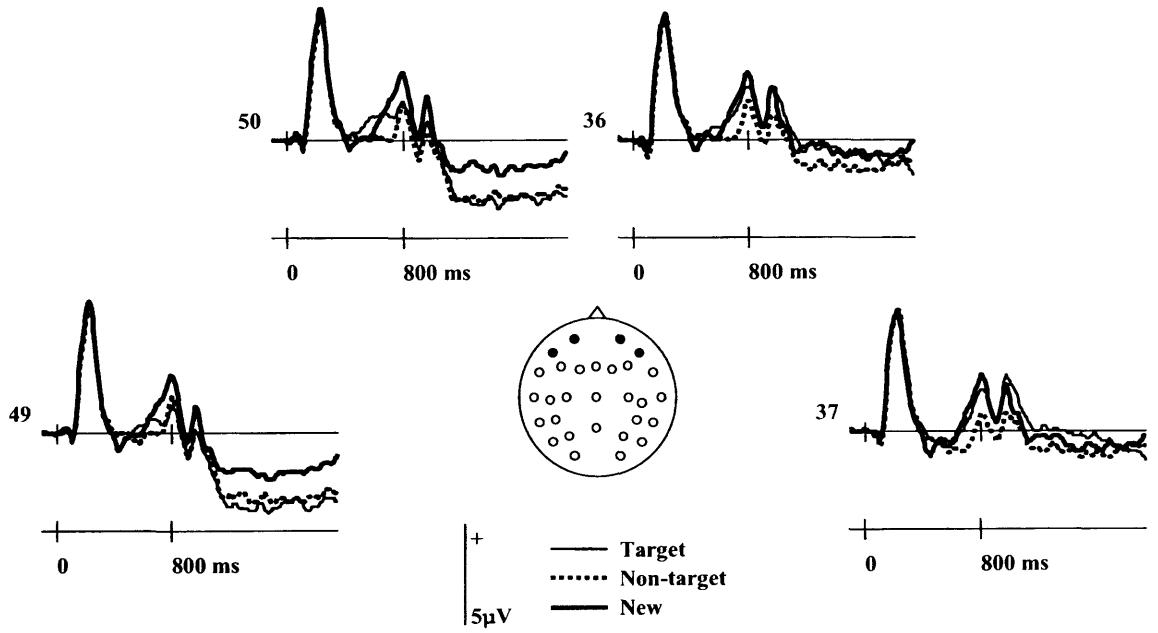

Figure 6.8.
Exp. 3 – Deep condition: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontopolar sites (49, 50, 37, 36).

5.58, p = 0.01]. The contrast between targets and new items revealed this same pattern of effects: a main effect of condition [F(1,15) = 7.12, p < 0.05]; an item x hemisphere interaction [*F*(1,15) = 8.12, p = 0.01]; a condition x item x hemisphere interaction [*F*(1,15) = 6.71, p < 0.05]; and a condition x item x hemisphere x site interaction [*F*(1,15) = 7.94, p = 0.01]. Subsidiary analysis revealed no significant effects for the shallow condition, although, for the deep condition, subsidiary analysis gave rise to interactions between item and hemisphere [*F*(1,15) = 10.19, p < 0.01], and between item, hemisphere and site [*F*(1,15) = 9.58, p < 0.01], reflecting reliable negative-going old/new effects for targets from the deep condition over left frontopolar sites, maximally at the left inferior frontopolar site. There were no significant effects involving the factor of item for the contrast between non-targets and new items across condition. The target/non-target contrast gave rise to interactions between condition, item and hemisphere [*F*(1,15) = 9.45, p < 0.01], and between condition, item, hemisphere and site [*F*(1,15) = 8.51, p = 0.01]. Subsidiary analyses revealed no significant effects for the shallow condition, but, for the deep condition, interactions between item and hemisphere [F(1,15) = 8.81, p = 0.01] and between item, hemisphere and site [F(1,15) = 9.09, p < 0.01], reflecting reliably greater positivity for targets at the right inferior frontopolar site.

1400-1900 msec

Shallow condition: ANOVA revealed interactions between item and site, and between item, location and site. Old/new contrasts revealed an item x site interaction for both targets and non-targets, in addition to an item x hemisphere x location interaction for non-targets only. These findings reflect negative-going old/new effects, maximal over superior sites for both targets and non-targets, as

well as over left frontal sites for non-targets, and a small, although unreliable, positivity for non-targets at inferior and right temporal sites. The contrast between targets and non-targets gave rise to interactions between item, hemisphere and location, and between item, location and site, reflecting greater negativity for targets, maximal at left parietal sites and bilateral inferior parietal sites, but slightly greater negativity for non-targets at superior / right parietal and mid-lateral frontal sites.

Deep condition: The global analysis gave rise to a number of item effects, including interactions between item and hemisphere, between item and site, and between item, hemisphere and location. Old/new contrasts revealed interactions between item, hemisphere and location for targets and non-targets, between item and hemisphere for targets, and between item and site for non-targets. These findings reflect positive-going old/new effects for targets over right frontal / temporal locations, but negative-going old/new effects over all other right and left hemisphere locations, maximal at left frontal sites. For non-targets, these findings reflect small positive old/new effects for non-targets at inferior sites, but negative-going old/new effects for the same items over all other sites, maximal but non-significant at superior and left frontal sites. The target / non-target contrast gave rise to an item x hemisphere interaction, reflecting greater negativity for targets over the left hemisphere, but greater negativity for non-targets over the right hemisphere, although these effects did not reach significance over either hemisphere.

Between condition: ANOVA contrasting target old/new effects across condition revealed a condition x hemisphere x location interaction [$F(1.4,23.9) =$

6.68, p = 0.01], reflecting negative-going old/new effects for targets from the shallow condition over all sites, greater over the left than the right hemisphere, and negative-going old/new effects for targets from the deep condition over most sites, maximal at left frontal sites, but small positive old/new effects for the same items at right frontal / temporal locations.

Bilateral frontopolar sites: The focused analysis conducted on data from frontopolar sites for the three item types across condition gave rise to a main effect of item [$F(2.0,29.7) = 3.36$, $p < 0.05$] and an item x hemisphere interaction [$F(1.9,28.9) = 4.71$, $p < 0.05$]. Old/new contrasts, across condition, revealed an item x hemisphere interaction for targets [$F(1,15) = 7.64$, $p < 0.05$] and for non-targets [$F(1,15) = 4.99$, $p < 0.05$], as well as a main effect of item for non-targets [$F(1,15) = 6.26$, $p < 0.05$], reflecting, for both types of item across condition, negative-going old/new effects, maximal and significant over left frontopolar sites. The target/non-target contrast revealed interactions between item and site, and between condition, item, hemisphere and site, reflecting greater negativity for non-targets over frontopolar sites, except at the right inferior frontopolar site for the shallow condition and at the left inferior frontopolar site for the deep condition where targets were more negative than non-targets. Subsidiary analyses revealed that these effects did not reach significance for either condition.

Topographic analyses

Analyses of the scalp topography of old/new effects proceeded in two stages. First, the distributions of old/new effects were compared across condition as well as the latency regions within which significant condition by scalp location interactions were revealed by the magnitude analyses directly contrasting old/new differences

across condition. These latency regions included 900-1100 and 1400-1900 msec for targets and 500-800; 900-1100 and 1100-1400 msec for non-targets. Second, within condition, reliable target and non-target old/new effects were contrasted for the latency regions within which the magnitude analyses indicated differences in the distribution of old/new effects across item type: 300-500, 900-1100 and 1400-1900 msec for the shallow condition; 900-1100 and 1100-1400 msec for the deep condition. The first set of ANOVAs, employing the factors of latency region, condition and site, provided no evidence that the scalp distribution of non-target old/new effects varied according to latency region or condition as there were no significant interactions between these factors and site. For targets, however, there was a significant latency region x condition x site interaction [$F(6.3,106.3) = 2.36$, $p < 0.05$], indicating that changes in the scalp distribution of target old/new effects across the two latency regions differed qualitatively between condition. As can be seen in figure 6.9, for the shallow condition, targets show a negativity with a mid-parietal maximum and a positivity over bilateral frontopolar regions during the 900-1100 msec latency region. This frontally-distributed positivity disappears during the 1400-1900 msec latency region as the mid-parietal negativity extends over left frontal regions. While targets from the deep condition also show a mid-parietal negativity during the 900-1100 msec latency region, small positive old/new effects are additionally distributed over right frontal and left parietal sites. This small parietal positivity disappears as a negativity emerges over left frontopolar regions during the 1400-1900 msec latency region. However, comparisons of the distribution of target old/new effects across condition within each of these latency

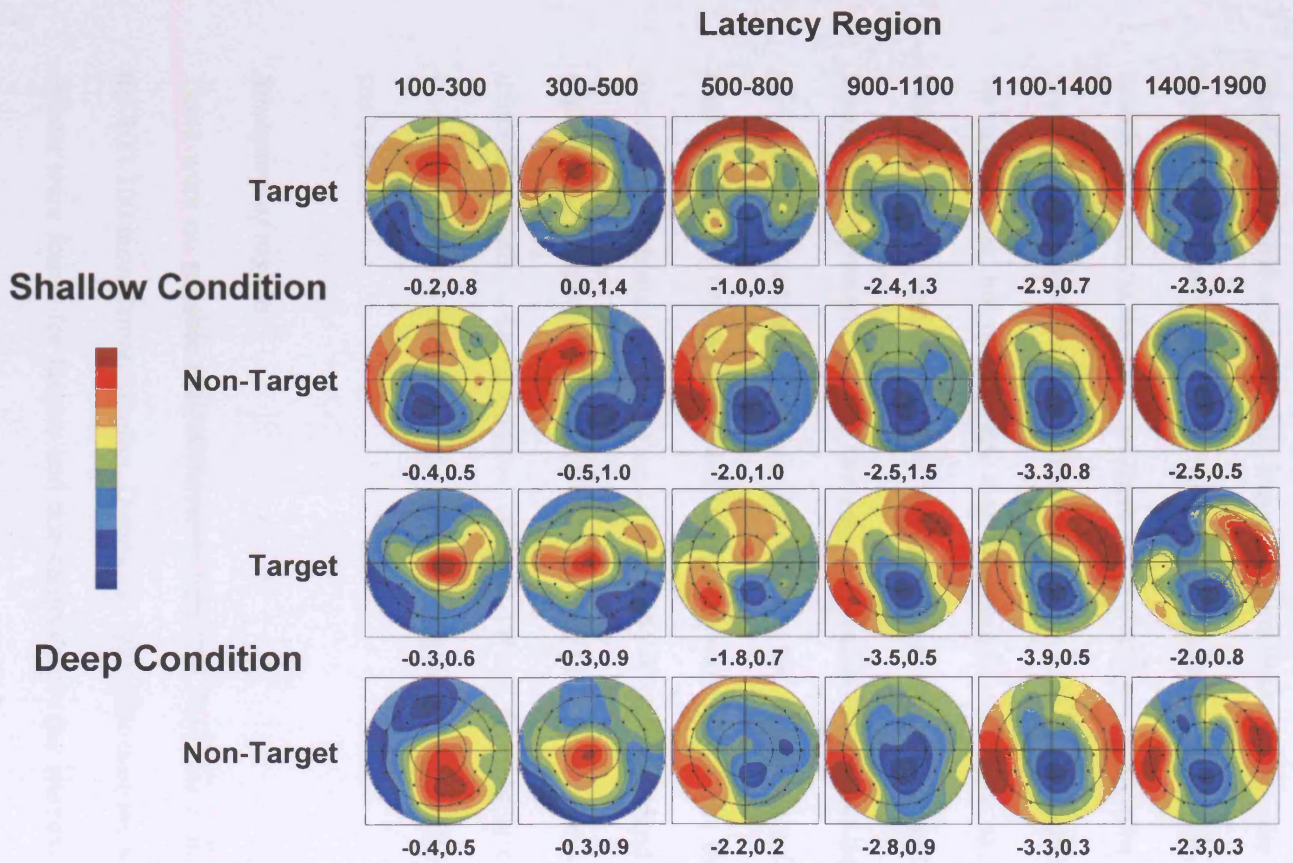

Figure 6.9.
Exp. 3 – Topographic maps of target and non-target old/new effects in the shallow condition and the deep condition for all latency regions as indicated. The paired values below each map indicate the voltage ranges (microvolts) of the differences between the two types of item (i.e., old-new) and can be interpreted with reference to the bar presented on the far left of the figure.

regions failed to reach significance when degrees of freedom were corrected for non-sphericity [F =1.5 for both latency regions]

The second set of analyses, employing the factors of item and site, revealed, for the 900-1100 msec latency region, a significant item x site interaction for the shallow condition [F(4.4,75.1) =4.40, p <0.005] As can be seen in figure 6.9, this interaction reflects the fact that there are positive-going old/new effects for targets, but not non-targets, over right frontopolar sites, and positive-going old/new effects for non-targets, but not targets, over left parietal sites. The same contrast for the 300-500 msec and 1400-1900 msec latency regions failed to give rise to interactions between item and site, providing no evidence that the scalp distribution of target and non-target effects differed for the shallow condition during these latency regions. For the deep condition, there were item x site interactions for both the 900-1100 msec latency region [F(3.5,59.5) =3.84, p =0.01]and the 1400-1900 msec latency region [F(3.4,58.2) =2.79, p <0.05] For both latency regions, these interactions reflect small positive old/new effects for targets over right frontal / frontopolar sites while non-targets show a negative-going old/new effect over the same sites.

Summary of results

There were no reliable ERP differences between items for either condition during the 100-300 msec latency region. During the 300-500 msec latency region, old/new effects were found for targets and non-targets from the shallow condition, but not the deep condition, although these old/new effects were widely distributed for targets, maximal over left inferior sites for non-targets, and did not reach significance at mid-frontal sites for either item. A left parietal old/new effect was

evident for non-targets from the shallow condition only during the 500-800 msec latency region. However, between 500-650 msec, short-lived left parietal effects were also elicited by targets from both conditions, although not by non-targets from the deep condition. Negative-going old/new effects were evident for all items, maximal at the right superior parietal site, from the 500-800 msec latency region for non-targets, and from the 900-1100 msec latency region for targets. This negativity was generally sustained for most items until the end of the recording epoch. During the same latency regions, a negativity was also apparent for targets and non-targets from the deep condition, but not the shallow condition, over left frontopolar / frontal sites, and was reflected by differences in the scalp distribution of target old/new effects only between the two conditions.

Discussion

Behaviour

Responses to targets and new items from the deep condition were more accurate than responses to the same items from the shallow condition, although non-target accuracy did not differ between the two conditions. Given that very little episodic information would have been available for targets from the shallow condition due to their superficial encoding, these findings reflect the fact that these items were less easily identified than targets from the deep condition. Furthermore, a higher false alarm rate to new items from the shallow condition suggests that there was a greater willingness to identify shallowly-encoded targets based on a sense of familiarity. In this case, target/non-target discrimination was, presumably, based on the recollection of non-target source. In contrast, when targets had been deeply encoded, the lower false alarm rate to new items and more accurate

responses to targets indicates that the successful recollection of target source provided the basis for accurate responding to targets in the deep condition (cf. Herron & Rugg, 2003a).

The accuracy data provided little evidence of differential processing of non-targets across condition and, therefore, whether or not discrimination of targets and non-targets from the deep condition additionally required the recollection of non-target source. However, responses to items from the deep condition were found to be quicker, overall, than to those from the shallow condition. Therefore, discrimination of targets and non-targets from the deep condition seems to have occurred more quickly than discrimination of the same items from the shallow condition, suggesting that target/non-target discrimination was based on different types of source-specifying information for each condition. This could, perhaps, indicate more rapid retrieval of source information for targets from the deep condition in comparison to that for non-targets from the shallow condition, or even the additional search required for non-target source information in the latter condition once target recollection had failed. Alternatively, slower RTs in the shallow condition may reflect less confidence and/or more difficulty associated with responses to items from this condition, related, perhaps, to repeated unsuccessful attempts to recollect target source.

ERPs

ERPs to targets did not significantly differ from those to non-targets or new items in either the shallow condition or the deep condition during the 100-300 msec latency region. Therefore, the hypothesis that it is the shallow encoding of target items, in contrast to the deep encoding of non-targets items, giving rise to the early

P2 modulation was not supported in this experiment. The present findings for the shallow condition are inconsistent with those for the (equivalent) word condition in Experiment 1 for which ERPs to targets were more positive than those to both non-targets and new items at a latency of 100-300 msec post-stimulus. As noted earlier, the P2 modulation within the context of recognition tasks may well be affected by the type of strategy used during the encoding and/or the retrieval phase, and it is conceivable that procedural differences between the two experiments may well have engendered differences in the specific strategies employed. In support of this idea, numerically, there were overall quicker responses and a greater number of false alarms for non-targets and new items in Experiment 1 (word condition) in comparison to those for the shallow condition in the present experiment. This suggests that the strategies employed in this latter condition led to a relatively less efficient, but more well-defined, search for target source information. This concurs with the finding of reliable, albeit short-lived, left parietal old/new effects found for targets from both conditions in the present experiment (see below).

As expected, correctly rejected non-targets elicited a left parietal old/new effect during the 500-800 msec latency region only when targets had been shallowly encoded (cf. Herron & Rugg, 2003a). These findings replicate those from Experiment 1 (word condition) indicating, as before, that it is necessary to retrieve non-target source information in order to correctly reject these items when memory for targets is poor. In contrast, the lack of a left parietal old/new effect during the 500-800 msec latency region for targets from the deep condition is inconsistent with findings of a robust left parietal old/new effect for deeply-encoded targets from the word condition in Experiment 2. This null finding in the

present experiment is also counter to the prediction that deeply-encoded targets would elicit a left parietal old/new effect, reflecting greater recollection for these items. However, it was apparent from the grand average waveforms that ERPs to deeply-encoded targets were, in fact, more positive-going than ERPs to new items over left parietal sites from around 400 msec, but became more negative-going from approximately 650 msec over the same sites as well as over most other sites across the scalp. To investigate this small positivity, a focused analysis during the 500-650 msec latency region was conducted, revealing a significant positive old/new effect for deeply-encoded targets over left parietal sites. As non-targets from the deep condition failed to elicit this effect, these findings can be seen to support the prediction that, with good memory for targets, a specific retrieval orientation can be adopted that allows processing resources to be selectively devoted to target recollection.

However, shallowly-encoded targets also elicited a positive old/new ERP effect during the 500-650 msec latency region over left parietal sites, suggesting that equivalent levels of recollection occurred for shallowly- and deeply-encoded targets. As accuracy for shallowly-encoded targets was poor, it is unlikely that this small positivity reflects vivid recollection for these items and, perhaps, instead, reflects processes underlying the retrieval of partial or less specified aspects of source information (Johnson *et al.*, 1993). This interpretation is supported by previous reports of successful source attributions based on the retrieval of partial source information (e.g., Dodson, Holland & Shimamura, 1998) as well as the finding that the left parietal old/new effect may index the amount of information retrieved from episodic memory in a graded, rather than 'all-or-none', fashion

(Wilding, 2000; see also Rugg, Cox, Doyle & Wells, 1995). In the present experiment, however, it would seem that, while the retrieval of such information was not sufficient to permit a discrimination between targets and non-targets from the shallow condition, this, nevertheless, allowed target/non-target discrimination in the deep condition.

One possible reason for this relates to a difference in levels of distinctiveness between targets and non-targets between the two conditions. For the shallow condition, the target study task required the presented word to be repeated out loud – the non-target study task also required the presented word to be spoken out loud but embedded within a self-generated sentence. Therefore, for successful target/non-target discrimination, information in addition to any vague sense of having spoken a word out loud would be required, in this case, through recollection of non-target source. Study tasks for the deep condition, however, requiring a pleasantness judgement for targets and sentence generation for non-targets, would have engendered comparatively fewer overlapping contextual features associated with the two item types. Therefore, for this condition, the retrieval of partial information, comprising even only a vague sense of having rated a word for pleasantness, would have been sufficient for a successful source decision. Additional support for this interpretation is given by the RT data which revealed quicker target/non-target discrimination in the deep condition, compared to the shallow condition. This is also consistent with the proposal that, in contrast to the relatively slow, intentional processes associated with vivid recollection, decisions based on partial source information may be executed relatively more quickly and heuristically (Johnson *et al.* 1993).

It could be argued that the left parietal old/new effect during the longer 500-800 msec latency region was, in fact, elicited by deeply-encoded targets but was simply obscured by the overlapping negativity occurring, maximally, at central/right superior parietal sites during the same latency region. However, this possibility does not negate the arguments offered above as this negativity was present for targets and non-targets from both conditions to a similar degree and, therefore, does not compromise the pattern of results as discussed. It is also quite possible that the presence of positive-going late frontal/frontopolar old/new effects, elicited by targets in Experiments 1 and 2, were obscured for targets in the present experiment by the overlap with the negative old/new effect. Negative-going old/new effects with a similar latency (onsetting at approximately 700 msec) and scalp distribution (maximally over central and posterior sites) to those found in the present experiment have been reported in a number of more recent ERP studies of episodic memory (e.g., Cycowicz, Friedman & Snodgrass, 2001; Dywan *et al.*, 2002; Wilding & Rugg, 1997; see Johansson & Mecklinger, 2003, for a review). Although there is little agreement as to the functional role of this ERP effect during memory retrieval, a number of proposals have been made: (1) action monitoring in tasks where there are high levels of response conflict (e.g., Nessler & Mecklinger, 2003); (2) processes related to searching for, or retrieving, colour-specific source information (Cycowicz *et al.*, 2001); (3) processes related to the formation and maintenance of the integrated representation of an item and its study context (Johansson & Mecklinger, 2003).

Certainly, in the present experiment, the retrieval of source information did not involve the retrieval of colour-specific information and, therefore, Cycowicz *et*

al.'s (2001) proposal does not apply to the findings reported here. With regard to the first proposal relating to action monitoring, it might have been expected, in this experiment, that targets and non-targets from the shallow condition would have elicited this negative-going effect to a greater extent than the same items from the deep condition. This is because the discrimination of targets and non-targets in the shallow condition, being more difficult compared to that in the deep condition, presumably engendered higher levels of response conflict. However, as targets and non-targets in the present experiment elicited the late negativity to a similar degree in both conditions, these findings do not support the idea that this effect is related to action monitoring in situations of high levels of response conflict. Findings from this experiment are most consistent with the proposal that this negative-going effect is related to the search for combined source-specifying information associated with the recognised item. As this proposal does not make any assumptions about retrieval success, a dissociation between the two conditions would not necessarily be predicted as a search for the conjunction of source and item information might be expected to occur for all familiar items. However, the present experiment provides no direct evidence for this proposal.

The most surprising results in the present experiment were the lack of early mid-frontal effects for targets and non-targets in both conditions. Early old/new effects were, however, elicited during the 300-500 msec latency region for targets and non-targets in the shallow condition only. Alongside the behavioural findings of low accuracy for targets and relatively high false alarms for new items in this condition, the early onset of this effect, preceding the onset of processes thought to support recollection, suggests that this early effect does reflect familiarity-based

recognition. However, the scalp distribution of this effect was found to be widely distributed across the scalp for targets and maximal over left inferior sites for non-targets. Furthermore, as there were no reliable old/new effects for targets or non-targets at mid-frontal sites, the spatial characteristics of this effect does not seem to be typical of the early mid-frontal old/new effect thought to reflect familiarity-based recognition reported in a number of previous studies (e.g., Curran, 2000; Curran & Cleary, 2003; Mecklinger, 2000; Rugg *et al.*, 1998). Nevertheless, when these early old/new effects were directly compared across condition, the effect was found to be greater for items from the shallow condition, maximally, over left frontal sites for targets and over left inferior sites for non-targets, similar to the scalp distributions reported for this early old/new effect reported in some previous studies (see Friedman & Johnson, 2000, for a review). Given proposals that familiarity may comprise a number of dissociable processes that each provide a basis for recognition, such as perceptual fluency and conceptual fluency (Jacoby, 1991; Jacoby & Dallas, 1981), it is conceivable that the spatial characteristics of the ERP correlate of familiarity may depend upon the particular component/s recruited.

In contrast to the above findings for targets and non-targets from the shallow condition, no reliable old/new effects were found for the same items from the deep condition during the 300-500 msec latency region. In the previous chapter, it was argued that the failure of non-targets to elicit early mid-frontal old/new effects may be due to the relatively long retention interval for these items. However, this explanation cannot account for the lack of mid-frontal effects for deeply-encoded targets in the present experiment. Although a number of

investigations support the proposal that the mid-frontal old/new effect reflects familiarity-based recognition (see Rugg & Yonelinas, 2003, for a review), this effect has not been consistently observed. For example, while the results of some investigations suggest that the mid-frontal effect reflects an amodal familiarity process (e.g., Curran & Dien, 2003), more recent findings indicate that this effect is sensitive to format change between an item's initial and subsequent encounter (Schloerscheidt & Rugg, 2004). Furthermore, the absence of mid-frontal effects have been reported both for repeated objects presented without their original context (Tsivilis *et al.*, 2001) as well as for repeated, pre-experimentally non-familiar faces (Yovel & Paller, 2004). Such evidence suggests that familiarity may not be generically indexed by the mid-frontal old/new effect. Interestingly, in non-human primates, neurons have been found to respond to repeated complex visual stimuli within 100 msec of their presentation (Xiang & Brown, 1998), an effect that has been proposed to reflect familiarity-based recognition (Brown & Bashir, 2002; Brown & Xiang, 1998). If this interpretation is correct, it would seem that the mid-frontal old/new effect occurs too late to directly reflect familiarity processing. In any case, given the more recent conflicting findings reviewed above (Schloerscheidt & Rugg, 2004; Tsivilis *et al.*, 2001; Yovel & Paller, 2004), as well as those reported in this thesis, it is becoming apparent that much work will be required to further evaluate the functional significance of this early mid-frontal effect.

Conclusion

Experiment 3 further investigated the earlier findings from Experiment 1 of an early P2 modulation elicited by shallowly-encoded targets. However, in the

present experiment, ERPs to targets did not differ significantly from those to non-targets or new items in either the shallow condition or the deep condition during the 100-300 msec latency region. Therefore, the hypothesis that it is the shallow encoding of targets, in contrast to the deep encoding of non-targets, giving rise to the early P2 modulation was not supported in this experiment. Other earlier findings, reported in this thesis, were, however, replicated in Experiment 3 – a left parietal old/new effect was elicited for correctly identified non-targets only when targets had been shallowly encoded. In contrast, when targets had been deeply encoded, non-targets failed to elicit this left parietal old/new effect. These findings are consistent with the notion that, when targets cannot be identified on the basis of retrieved information diagnostic of their study source, it is necessary to retrieve non-target source information in order to reject these items. However, when there is good memory for targets, the adoption of a specific 'retrieval orientation' allows test cues to selectively probe memory for targets at the expense of non-target recollection. Finally, the lack of early mid-frontal old/new effects for targets and non-targets in either the shallow condition or the deep condition in Experiment 3 adds to other accruing evidence that familiarity may not, in fact, be generically indexed by this early mid-frontal modulation.

CHAPTER 7

Recall-to-reject and contextual discrimination: The influence of contextual distinctiveness on the control of recollection in exclusion tasks:

Experiment 4

Introduction

In agreement with other recent ERP studies employing the exclusion task (Dywan *et al*, 2002; 1998; 2001; Herron & Rugg, 2003a; 2003b), findings reported in this thesis have shown that, under certain circumstances, correctly rejected non-targets may fail to elicit a left parietal old/new ERP effect. Given that this effect is held to reflect processes of recollection, these findings provide evidence in support of the proposal that it may not always be necessary to retrieve non-target study source in order to correctly reject these items (Herron & Rugg, 2003a). It would seem that, when there is good memory for targets, a specific retrieval orientation may be adopted, allowing test cues to selectively probe memory for target information at the expense of non-target recollection. An outstanding question arising from these findings, however, is why left parietal old/new effects for correctly rejected non-targets have sometimes been reported even when target accuracy has been high (e.g., Cycowicz *et al.*, 2001; 2003; Wilding & Rugg, 1997; Wilding & Sharpe, 2004). Such inconsistent findings indicate that there are factors, in addition to target memorability, that may influence the recollection of non-targets.

Presumably, the adoption of a specific retrieval orientation, allowing test cues to selectively probe memory for target source information, is most likely to be successful when there are few overlapping contextual features associated with targets and non-targets. If this is correct, one factor that should modulate non-target recollection is the degree of similarity between target and non-target study contexts (see also Wilding & Sharpe, 2004, for a similar proposal). Consistent with this idea, in Experiment 3 of this thesis, not only did the shallow and deep conditions differ with respect to depth of target encoding, but they also differed in terms of the distinctiveness of contextual information associated with targets. Accordingly, for the deep condition, the study task associated with targets (pleasantness rating), being quite distinct from that associated with non-targets (sentence generation), provided unique source-specifying information for these items. In this case, it would seem possible to probe memory for source information that was uniquely associated with targets – this is supported by evidence, in the deep condition, of a left parietal old/new effect for targets, but not for non-targets. In contrast, for the shallow condition, only the study task associated with non-targets provided unique source-specifying information. In this latter condition, the target study task required each word to be simply repeated aloud while the non-target study task required each word to be incorporated within a self-generated sentence which was also to be spoken aloud. In this case, simply remembering that a word had been spoken aloud would have been redundant in terms of discriminating between targets and non-targets – retrieving the sentence in relation to repeating the word aloud would have been necessary for this discrimination and this distinct information was associated with non-targets only. The finding of a left parietal

old/new effect for non-targets in the shallow condition would seem to reflect the necessity to retrieve non-target source information in this condition.

In accord with the above view, the absence of a left parietal old/new effect for non-targets has been reported for studies in which unique source specifying information has been associated with the target study task: repeating presented study words aloud and remembering for a later test (targets) versus passively seeing repeated foils that were presented only at test (non-targets) (Dywan *et al*, 2002; 1998; 2001); pleasantness rating (targets) versus sentence generation (non-targets) (Herron & Rugg, 2003a). Conversely, ERP studies reporting robust left parietal old/new effects for non-targets have employed study tasks that have led to a considerable overlap in the contextual information associated with targets and non-targets: naming the colour of target and non-target pictures (red or green) (Cycowicz *et al.*, 2001; 2003); specifying whether target and non-target words were spoken in a male or female voice (Wilding & Sharpe, 2004). For these latter experiments, although targets and non-targets could be discriminated by the particular colour, or voice, they had been presented with at study, presumably, the cognitive operations engaged in identifying these percepts during the study phase would have been very similar for the two item types. Therefore, it would seem that the recollection of such items will involve not only the retrieval of their associated perceptual features engendered during study, but also the cognitive operations that led to the identification of such features.

In line with the above observations, the present experiment investigated whether the ERP correlates of recollection would differ according to the degree of similarity between target and non-target study contexts. For the 'similar group',

target and non-target study tasks were identical and, for the 'different group', target and non-target study tasks were more distinct. For both groups, study tasks were chosen to elicit good memory for both targets and non-targets. Given greater similarity between target and non-target study contexts, attempts to retrieve target source should, to some extent, give rise to the recollection of non-targets. Therefore, for the similar group, it was predicted that correctly rejected non-targets would elicit a left parietal old/new ERP effect. However, with greater differences between target and non-target study contexts, a retrieval strategy allowing exclusive recollection of target source should be more successfully adopted such that non-targets could be rejected on the basis of the absence of this information. Therefore, it was predicted that, for the different group, non-targets will fail to elicit a left parietal old/new ERP effect.

Method

Participants

Forty one students participated in the experiment. However, data from 9 of these were discarded due to the failure to provide 16 or more artefact-free trials for one or more of the critical conditions. Of the remaining 32 participants, 8 males and 8 females (age range 18-29 years; mean age 22 years) were assigned to the 'similar' group, and another 7 males and 9 females (age range: 18-29 years; mean age: 21 years) were assigned to the 'different' group. All participants had normal red-green colour vision as determined by Ishihara's tests for colour deficiency, concise edition (Ishihara, 2002).

Design overview

A 2 (group: similar; different) x 3 (item: targets; non-targets; new items) mixed factorial design was employed, with group as a between-subjects factor and item as a within-subjects factor. For each group, the experiment consisted of one block comprising three phases; study list 1, study list 2 and test. Figure 7.1 provides an overview of the design. For the purposes of this experiment, each participant completed one study-study-test block. For both groups, non-target and target study lists (i.e., study lists 1 and 2, respectively) could be discriminated by the colour associated with each list – words from one list were presented in red and words from the other list were presented in green. A colour association task was required for non-target and target study lists to ensure participants attended to the colour associated with these lists. The similarity of non-targets and targets was manipulated between groups with the use of a second study task – the

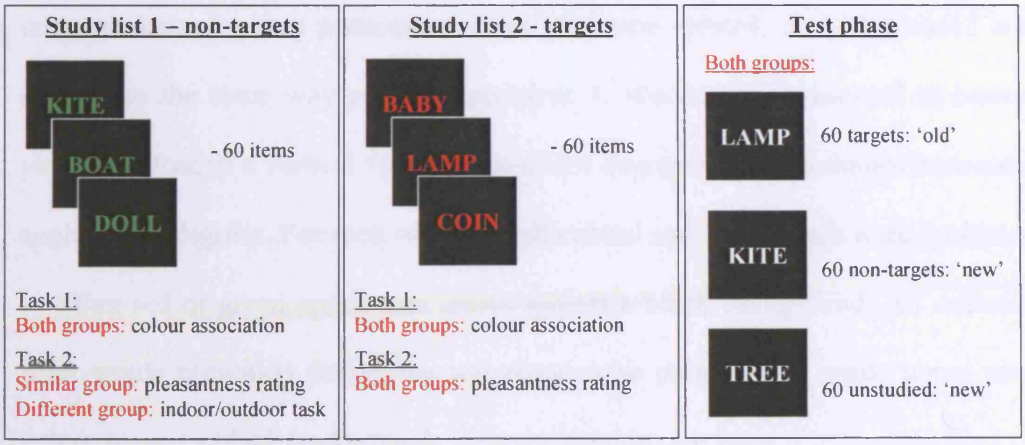

Figure 7.1.
Exp. 4 – design. Study-study-test block depicting study tasks for each group, with examples of study/test items and their correct responses at test. Retaining the above correspondence of group to study task, word colour and tasks were fully counterbalanced across study list and group.

pleasantness rating task or the 'indoor/outdoor' task. For the similar group, participants completed the same task for non-target and target study lists; for the different group, participants completed different tasks for non-target and target study lists. The colour and task contexts were orthogonally counterbalanced across participants such that an equal number of participants experienced one of four contextual combinations associated with targets: (1) colour red +pleasantness rating; (2) colour red +indoor/outdoor; (3) colour green +pleasantness rating; (4) colour green +indoor/outdoor.

Stimuli and procedures

The stimulus set, methods and procedures employed were almost identical for each experimental group except for those noted below. The stimulus set was the same as that used in Experiment 3. The 4 study lists of 60 critical words (and 2 filler words) – A, B, C and D – served equally often as non-target and target items. Four non-target/target study list sequences – A/B, D/A, C/D, B/C – were counterbalanced across participants. Test lists were created, counterbalanced and ordered in the same way as for Experiment 3. Words were presented in central vision, subtended a vertical visual angle of 0.4 degrees and a maximum horizontal angle of 2.0 degrees. For each study list, all critical and filler words were presented in either red or green upper case letters against a black background. All critical / filler words presented during the test phase were presented in white upper case letters against a black background.

For each word presented during both the non-target and target study phases, participants were required to complete two study tasks. The first of these was a visualisation task. This task required participants to name out loud the colour the

word had been presented in (red or green) and to incorporate this colour into a visualisation of the object represented by the word in a meaningful way. For example, if the word 'bus' had been presented in the colour red, a participant might name out loud the word 'red' while visualising themselves running for a red double-decker London bus. For the second task, participants were required either to rate the meaning of each word for pleasantness on a scale from 1 (unpleasant) to 5 (pleasant), or to verbally indicate whether the object depicted by the word is more likely to be found indoors or outdoors. Participants were encouraged to complete these tasks in quick succession. Both colour and task assignment were determined by group, study list and the counterbalancing procedures as described above under 'Design overview'. Instructions for the test phase for each group were identical to those given in Experiments 1, 2 and 3. EEG and EOG recording parameters, trial rejection criteria and blink correction procedures were also identical to those employed in Experiments 1, 2 and 3.

Results

Behavioural data

Accuracy and reaction time data from each group are summarised in Table 7.1. A 2 (group: similar; different) x 3 (item: targets; non-targets; new items) mixed design ANOVA revealed a main effect of item [$F(2,60) = 64.57$, $p < 0.001$] There were no significant effects involving the factor of group, either as a main effect ($F < 1$) or as an interaction with item ($F < 1$). Pair wise contrasts revealed that responses to new items were more accurate than responses to both targets [$F(1,31) = 109.44$, $p < 0.001$]and non-targets [$F(1,31) = 114.97$, $p < 0.001$] and that responses to targets were more accurate than those to non-targets [$F(1,31) = 6.10$, $p < 0.05$]

Table 7.1.
Exp. 4 – Mean percent accuracy and reaction time (including standard deviations) for correctly classified targets, non-targets and new items as a function of group.

GROUP	ITEM TYPE	% CORRECT	RT (SD)
Similar	Targets	80 (10)	1400 (216)
	Non-targets	76 (11)	1511 (219)
	New	98 (2)	1221 (219)
Different	Targets	84 (8)	1302 (162)
	Non-targets	77 (12)	1444 (193)
	New	98 (2)	1141 (157)

A 2 x 3 mixed design ANOVA performed on the RT data gave rise to a main effect of item [$F(1.6,48.3) = 121.40$, $p < 0.001$] but revealed no significant main effect of group ($F < 1$) and no gr oup x item interaction ($F = 1.5$). Pairwise tests revealed that, across group, responses to new items were significantly faster than those to both targets [$F(1,15) = 108.33$, $p < 0.001$]and non-targets [$F(1,15) = 166.62$, $p < 0.001$] and that responses to targets were significantly faster than those to non-targets [$F(1,15) = 58.05$, $p < 0.001$]

ERP data

The mean number (and range) of trials contributing to averaged ERPs associated with targets, non-targets and new items were 41 (26-52), 37 (20-48) and 50 (40-59) respectively for the similar group and 44 (30-52), 40 (16-53) and 51 (37-59) respectively for the different group. Grand average waveforms associated with the three item types for the similar and different groups are shown at selected

lateral electrode sites in figures 7.2 and 7.3, respectively, and for both groups at mid-line electrode sites in figure 7.4. Relative to new item ERPs, target ERPs from both groups and non-target ERPs from the different group show greater positivity, particularly at superior and mid-frontal sites, between approximately 300-500 msec post-stimulus. This positivity is not apparent for non-targets from the similar group at the same sites. However, at around 200-300 msec post-stimulus, a very early left-parietal old/new effect seems to emerge for non-targets from the similar group which is sustained, maximally, at the left superior parietal site until around 700 msec post-stimulus. Early-onsetting left parietal old/new effects can also be seen for targets, lasting between around 200-1100 msec post-stimulus for targets from the similar group and between approximately 300-800 msec post-stimulus for targets from the different group. Only a very small, short-lived left parietal effect can be seen for non-targets from the different group – instead, these items show a greatly enhanced negativity from around 700 msec post-stimulus, particularly over superior parietal sites and, maximally, at the mid-parietal site. Similar negative-going old/new effects are also apparent for targets from the different group and for targets and non-targets from the similar group, although, for these items, this negativity seems to be much smaller in magnitude. Finally, from around 1100 msec post-stimulus, positive old/new effects, notably over right frontal sites, are apparent, particularly for targets from both groups but, also, to a much lesser extent, for non-targets from both groups.

Experiment 4 used a similar ERP analysis strategy to that used in Experiment 3. First, global analyses were performed on data from targets, non-targets and new items, for each group separately, at the same lateral frontal,

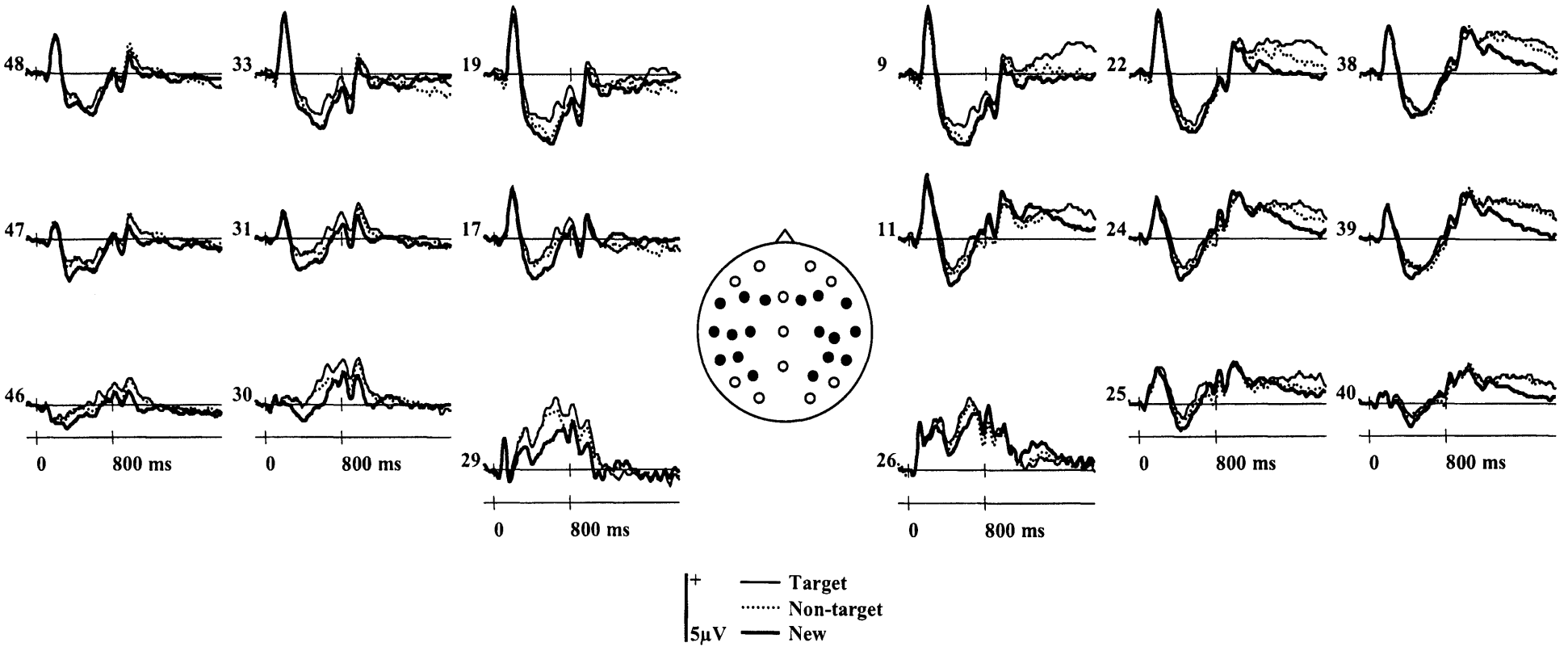

Figure 7.2.
Exp. 4 – Similar group: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at lateral frontal (48, 33, 19, 38, 22, 9), lateral temporal (47, 31, 17, 29, 24, 11) and lateral parietal sites (46, 30, 29, 40, 25, 26).

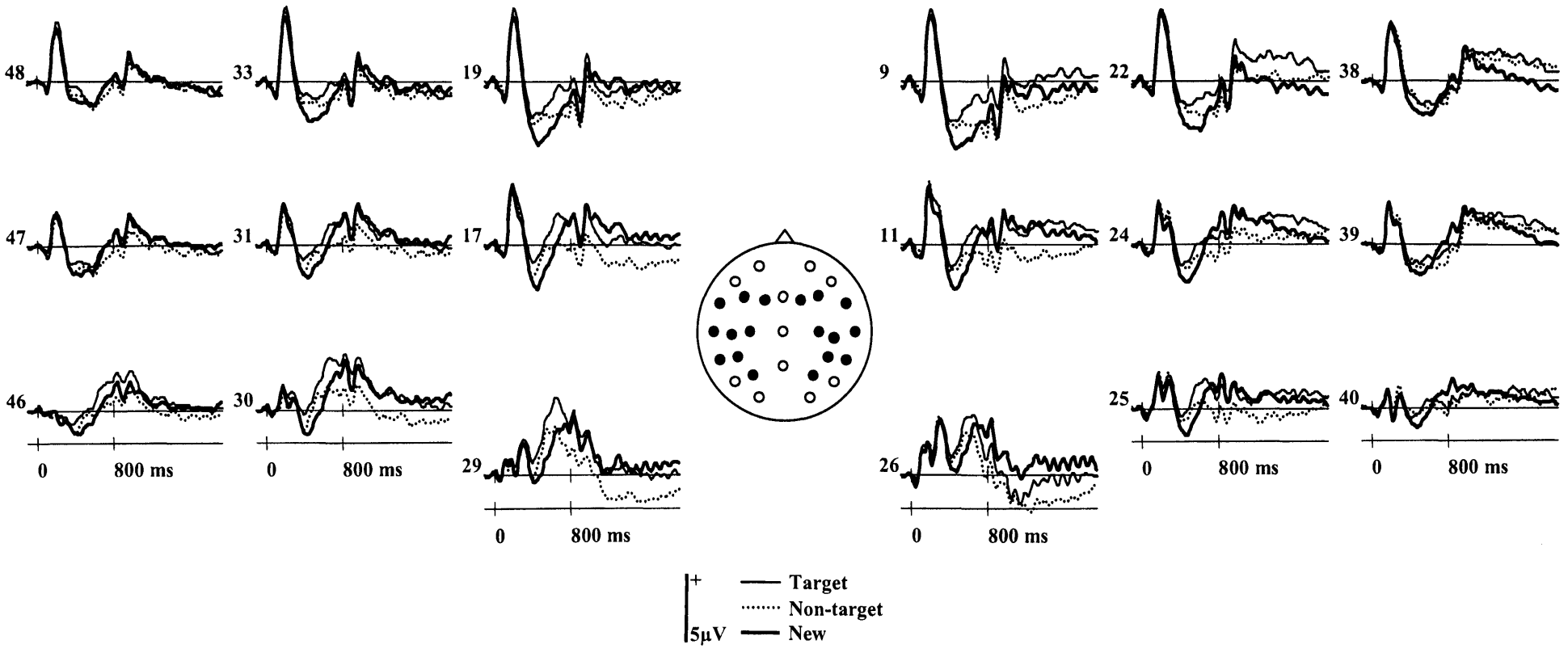

Figure 7.3.
Exp. 4 – Different group: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at electrode sites as described in Figure 7.2.

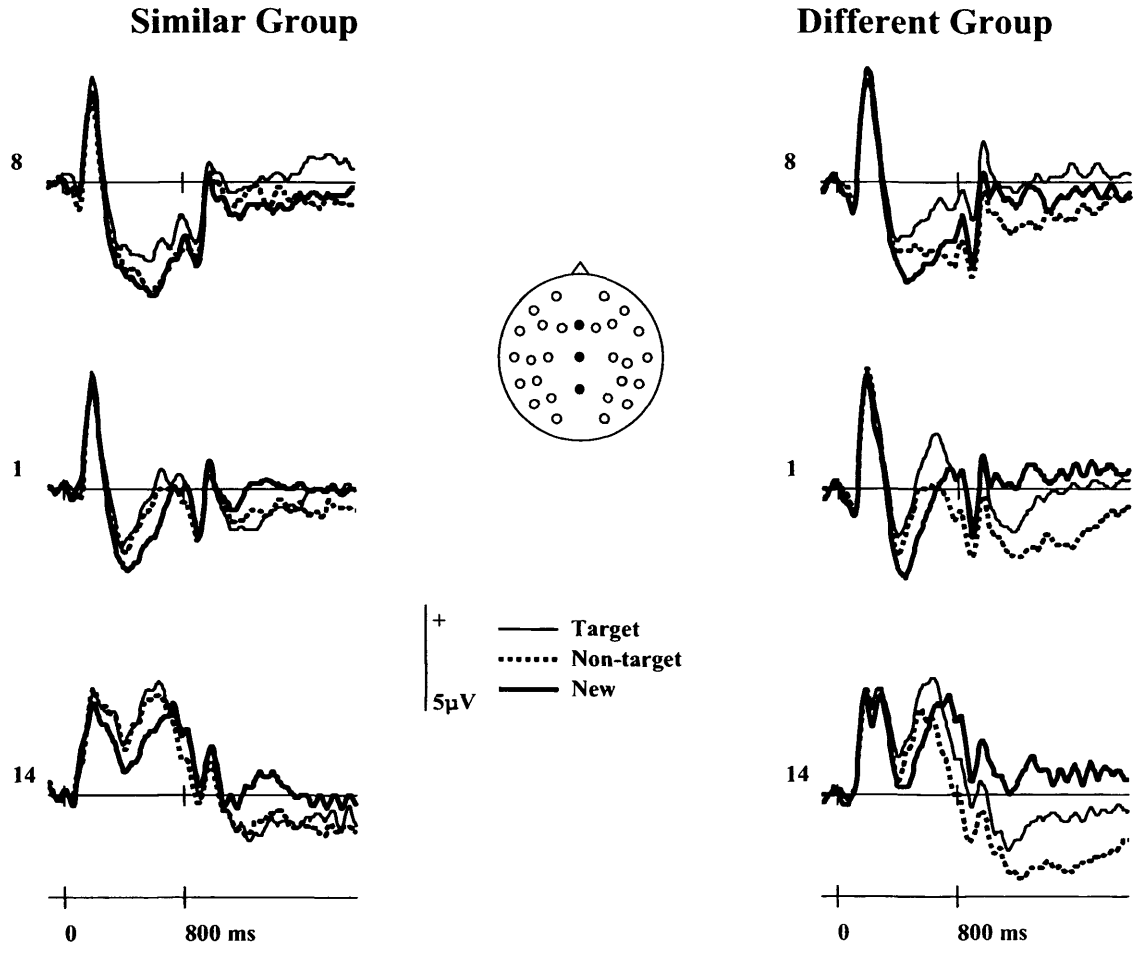

Figure 7.4.
Exp. 4: Grand average ERP waveforms elicited by correctly classified targets, non-targets and new items at mid-line sites (8, 1, 14) for the similar group (left column) and the different group (right column).

temporal and parietal sites as was chosen for Experiment 3 (see Chapter 4 for further details). These global analyses were conducted within five latency regions (300-500 msec; 500-800 msec; 900-1100 msec; 1100-1400 msec; 1400-1900 msec) and employed the factors of item, hemisphere, location and site. The results of these are shown in tables 7.2 and 7.3 for the similar group and the different group respectively. Two sets of mixed design global ANOVAs were also conducted within each of the latency regions described above. The first of these compared

Table 7.2.
Exp. 4 – Summary of ANOVA results in each ERP latency region for the similar group.

	300-500 msec	500-800 msec	900-1100 msec	1100-1400 msec	1400-1900 msec
Targets/non-targets/new					
IT	$F_{1.9,29.1} = 5.03$, $p = 0.01$	$F_{1.9,28.5} = 5.16$, $p = 0.01$	–	–	–
IT x HM	–	–	$F_{1.6,23.8} = 4.17$, $p < 0.05$	–	$F_{1.7,26.1} = 4.60$, $p < 0.05$
IT x ST	–	$F_{2.1,31.0} = 5.78$, $p < 0.01$	–	–	–
IT x HM x AP	$F_{2.7,40.6} = 3.33$, $p < 0.05$	–	–	–	$F_{3.1,46.4} = 2.94$, $p < 0.05$
IT x AP x ST	–	–	–	$F_{3.6,54.7} = 3.52$, $p < 0.05$	$F_{3.7,55.0} = 2.99$, $p < 0.05$
Targets/new					
IT	$F_{1,15} = 11.14$, $p = 0.005$	$F_{1,15} = 8.96$, $p < 0.01$	–	–	$F_{1,15} = 5.01$, $p < 0.05$
IT x HM	–	–	$F_{1,15} = 4.78$, $p < 0.05$	–	$F_{1,15} = 7.94$, $p = 0.01$
IT x ST	–	$F_{1.1,16.7} = 9.76$, $p = 0.005$	–	–	–
IT x AP x ST	–	–	$F_{2.5,37.7} = 3.12$, $p < 0.05$	$F_{2.6,39.5} = 5.99$, $p < 0.005$	$F_{2.6,39.4} = 5.29$, $p = 0.005$
IT x HM x AP x ST	–	$F_{3.1,46.2} = 3.19$, $p < 0.05$	$F_{3.1,46.7} = 3.24$, $p < 0.05$	–	–
Non-targets/new					
IT x HM	–	$F_{1,15} = 6.42$, $p < 0.05$	$F_{1,15} = 6.23$, $p < 0.05$	–	$F_{1,15} = 6.82$, $p < 0.05$
IT x ST	–	–	–	$F_{1.1,16.2} = 5.95$, $p < 0.05$	$F_{1.2,17.7} = 8.87$, $p < 0.01$
IT x HM x AP	$F_{1.8,27.2} = 7.14$, $p < 0.005$	–	–	–	$F_{1.6,24.6} = 5.01$, $p < 0.05$
IT x AP x ST	–	–	–	$F_{2.0,30.5} = 3.88$, $p < 0.05$	–
Targets/non-targets					
IT	–	$F_{1,15} = 4.71$, $p < 0.05$	–	–	–
IT x AP	–	–	–	–	$F_{1.2,17.9} = 5.20$, $p < 0.05$

IT = item type; HM = hemisphere; AP = location; ST = site.

Table 7.3.
Exp. 4 – Summary of ANOVA results in each ERP latency region for the different group.

	300-500 msec	500-800 msec	900-1100 msec	1100-1400 msec	1400-1900 msec
Targets/non-targets/new					
IT	$F_{1.9,28.2} = 4.80$, $p < 0.05$	$F_{1.9,29.2} = 4.94$, $p < 0.05$	$F_{1.7,25.8} = 3.57$, $p < 0.05$	$F_{1.9,28.9} = 4.03$, $p < 0.05$	–
IT x AP	–	–	–	$F_{1.6,23.8} = 4.71$, $p < 0.05$	$F_{1.7,25.2} = 8.42$, $p < 0.005$
IT x ST	$F_{2.1,31.8} = 3.37$, $p < 0.05$	$F_{2.1,32.1} = 7.26$, $p < 0.005$	–	$F_{2.1,31.8} = 10.81$, $p < 0.001$	$F_{2.4,35.8} = 9.77$, $p < 0.001$
IT x HM x AP	–	$F_{2.9,44.0} = 6.97$, $p = 0.001$	$F_{2.5,37.7} = 7.15$, $p = 0.001$	$F_{2.9,42.9} = 9.13$, $p < 0.001$	$F_{2.9,43.9} = 3.58$, $p < 0.05$
IT x HM x ST	–	–	–	–	$F_{2.3,35.1} = 3.39$, $p < 0.05$
Targets/new					
IT	$F_{1,15} = 7.81$, $p = 0.01$	$F_{1,15} = 6.53$, $p < 0.05$	–	–	–
IT x AP	–	–	–	–	$F_{1.1,17.2} = 4.29$, $p = 0.05$
IT x ST	$F_{1.0,15.7} = 5.69$, $p < 0.05$	$F_{1.1,16.2} = 11.87$, $p < 0.005$	–	$F_{1.1,16.9} = 4.51$, $p < 0.05$	–
IT x HM x AP	–	$F_{1.9,28.7} = 10.30$, $p < 0.001$	$F_{1.8,26.7} = 8.24$, $p < 0.005$	$F_{1.7,25.9} = 14.15$, $p < 0.001$	$F_{1.8,27.1} = 5.49$, $p = 0.01$
IT x AP x ST	–	$F_{1.5,23.2} = 5.28$, $p < 0.05$	–	–	–
Non-targets/new					
IT	$F_{1,15} = 5.05$, $p < 0.05$	–	$F_{1,15} = 6.16$, $p < 0.05$	$F_{1,15} = 6.04$, $p < 0.05$	–
IT x AP	–	–	$F_{1.2,18.5} = 4.58$, $p < 0.05$	$F_{1.1,16.8} = 9.38$, $p < 0.01$	$F_{1.1,16.6} = 13.36$, $p < 0.005$
IT x ST	–	–	$F_{1.3,19.3} = 7.72$, $p < 0.01$	$F_{1.2,18.7} = 28.81$, $p < 0.001$	$F_{1.2,18.2} = 19.45$, $p < 0.001$
IT x HM x ST	–	–	–	–	$F_{1.5,22.8} = 7.52$, $p < 0.01$
Targets/non-targets					
IT	–	$F_{1,15} = 7.26$, $p < 0.05$	–	$F_{1,15} = 5.10$, $p < 0.05$	$F_{1,15} = 4.97$, $p < 0.05$
IT x AP	–	–	–	–	$F_{1.7,26.1} = 6.90$, $p = 0.005$
IT x ST	–	$F_{1.1,16.3} = 7.80$, $p = 0.01$	–	$F_{1.1,17.0} = 5.43$, $p < 0.05$	$F_{1.2,18.6} = 7.48$, $p = 0.01$
IT x HM x AP	–	$F_{1.7,26.2} = 5.53$, $p = 0.01$	$F_{1.8,27.6} = 10.20$, $p = 0.001$	$F_{1.8,27.4} = 7.05$, $p < 0.005$	–

IT = item type; HM = hemisphere; AP = location; ST = site.

reliable target and non-target old/new effects between groups and employed the factors of group, hemisphere, location and site. The second set of mixed design global ANOVAs compared ERPs associated with correctly rejected new items across group and employed the factors of group, hemisphere, location and site. For this latter set of analyses, only those revealing significant effects involving the factor of group will be reported. Focused analyses were conducted on data from mid-frontal sites within the 300-500 msec latency region and from lateral parietal sites within the 500-800 msec latency region. As the global waveforms seem to show an early left parietal old/new effect emerging for non-targets from the similar group, but not for the same items from the different group, analyses were also conducted on data from lateral parietal sites within the 300-500 msec latency region. Focused analyses were not conducted on data from lateral frontopolar sites during the 900-1100 msec, 1100-1400 msec and 1400-1900 msec latency regions in this experiment as it would appear that right frontal effects are likely to be captured within the global analysis and because these show no obvious dissociations between the two groups. As mentioned in the previous experimental chapter, a late negative-going old/new effect has been increasingly reported in more recent ERP studies of episodic memory. As can be seen from the waveforms at mid-line sites in this experiment, this effect tends to be maximal at the mid-parietal (Pz) site. The global analyses in this experiment, however, do not include this site. Therefore, as this late negativity, in this experiment, seems to be much larger for non-targets from the different group in comparison to those from the similar group, particularly at the mid-parietal site, additional focused analyses were conducted on data from this site (Pz) during the 1100-1400 msec and 1400-1900

msec latency regions. For these focused analyses, the factors of group and item, as well as hemisphere and/or site were employed. Topographic analyses were also conducted, when appropriate, to determine whether reliable target and non-target old/new effects differed qualitatively, both within and across group, as well as across different latency regions.

Magnitude analyses

300-500 msec

Similar group: The global analysis revealed a main effect of item and an item x hemisphere x location interaction. Old/new contrasts gave rise to a main effect of item for targets and an item x hemisphere x location interaction for non-targets. There were no significant effects for the target/non-target contrast. These findings reflect positive-going old/new effects for both types of old item, an effect which is widely distributed across the scalp for targets, but significant only at left temporal and (maximally) at left parietal sites for non-targets.

Different group: ANOVA gave rise to a main effect of item and an item x site interaction. Pairwise contrasts between old and new items found main effects of item for targets and non-targets and, additionally, an interaction between item and site for targets. The target/non-target contrast revealed no significant effects involving the factor of item. These findings reflect positive-going old/new effects for both types of old item, an effect which is widely distributed across the scalp for non-targets and maximal at superior sites for targets.

Between-group: ANOVA, contrasting target old/new effects between group, failed to give rise to any significant effects involving the factor of group. However, the analysis comparing non-target old/new effects between group

revealed interactions between group and location [$F(1.4,41.7) = 3.83$, $p < 0.05$] as well as between group, hemisphere and location [$F(1.6,49.2) = 3.94$, $p < 0.05$]. These latter findings reflect the fact that, while positive non-target old/new effects are apparent for both groups, these are maximal over left parietal sites for the similar group, but maximal over frontal sites for the different group.

Mid-frontal sites: The *a priori* analysis over mid-frontal sites for the three item types across group gave rise to a main effect of item [$F(1.9,58.5) = 6.03$, $p < 0.005$]. Main effects of item were found for the contrasts between targets and new items [$F(1,30) = 10.56$, $p < 0.005$] and between non-targets and new items [$F(1,30) = 4.07$, $p = 0.05$]. There were no significant effects for the contrast between targets and non-targets. These findings reflect, across group, positive old/new effects for targets and non-targets at mid-frontal sites (see figure 7.5).

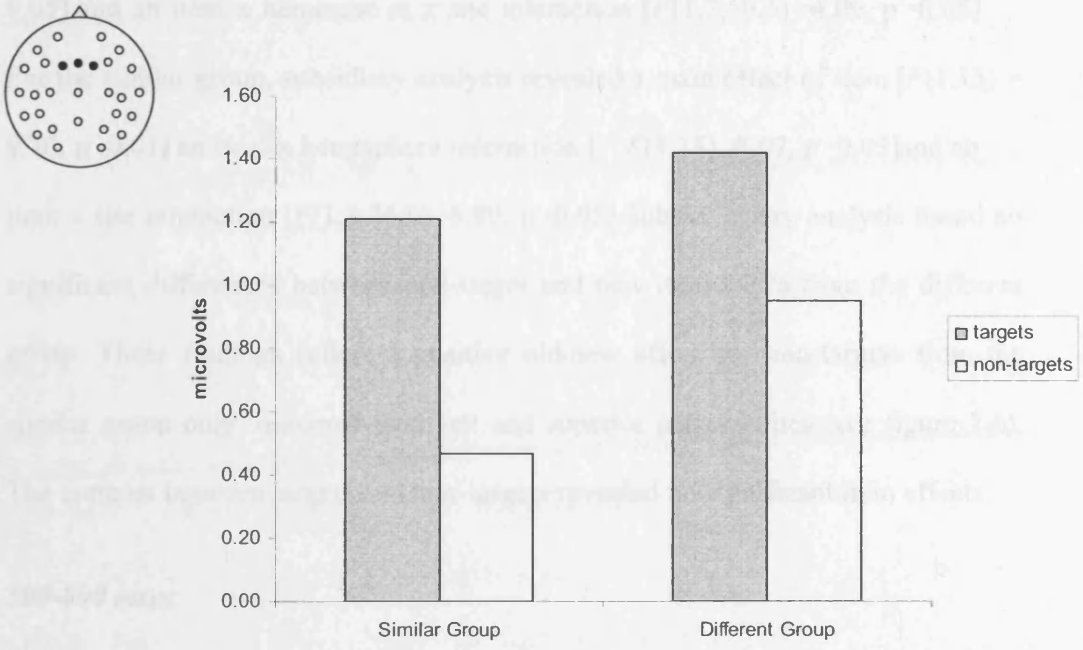

Figure 7.5.
Exp. 4 – Mean amplitudes (μV) of target and non-target old/new effects for the similar group (left) and the different group (right) over the 300-500 msec latency region. The mean amplitudes are collapsed across the three mid-frontal sites as indicated.

Bilateral parietal sites: The focused analysis conducted on data from all three item types across group over lateral parietal sites revealed a main effect of item [$F(2.0,59.8) = 11.02$, $p < 0.001$] along with interactions between item and site [$F(2.4,72.6) = 3.64$, $p < 0.05$] and between item, hemisphere and site [$F(3.1,91.5) = 3.13$, $p < 0.05$] The contrast between targets and new items revealed a main effect of item [$F(1,30) = 21.35$, $p < 0.001$] an item x site interaction [$F(1.5,45.7) = 9.53$, $p = 0.001$] reflecting, across group, greater positivity for targets, compared to new items, maximal at superior parietal sites. However, there was also a marginally significant item x hemisphere x site interaction [$F(1.5,46.0) = 3.27$, $p < 0.06$] indicating that this effect is lateralised to the left superior parietal site. The contrast between non-targets and new items gave rise to a main effect of item [$F(1,30) = 11.01$, $p < 0.005$] a group x item x hemisphere interaction [$F(1,30) = 6.01$, $p < 0.05$] and an item x hemisphere x site interaction [$F(1.7,50.5) = 4.09$, $p < 0.05$] For the similar group, subsidiary analysis revealed a main effect of item [$F(1,15) = 9.70$, $p < 0.01$] an item x hemisphere interaction [$F(1,15) = 7.07$, $p < 0.05$] and an item x site interaction [$F(1.8,26.9) = 3.99$, $p < 0.05$] Subsidiary analysis found no significant differences between non-target and new item ERPs from the different group. These findings reflect a positive old/new effect for non-targets from the similar group only, maximal over left and superior parietal sites (see figure 7.6). The contrast between targets and non-targets revealed no significant item effects.

500-800 msec

Similar group: The global analysis revealed a main effect of item and an item x site interaction. The same pattern of effects was evident for the contrast between targets and new items, in addition to an interaction between item,

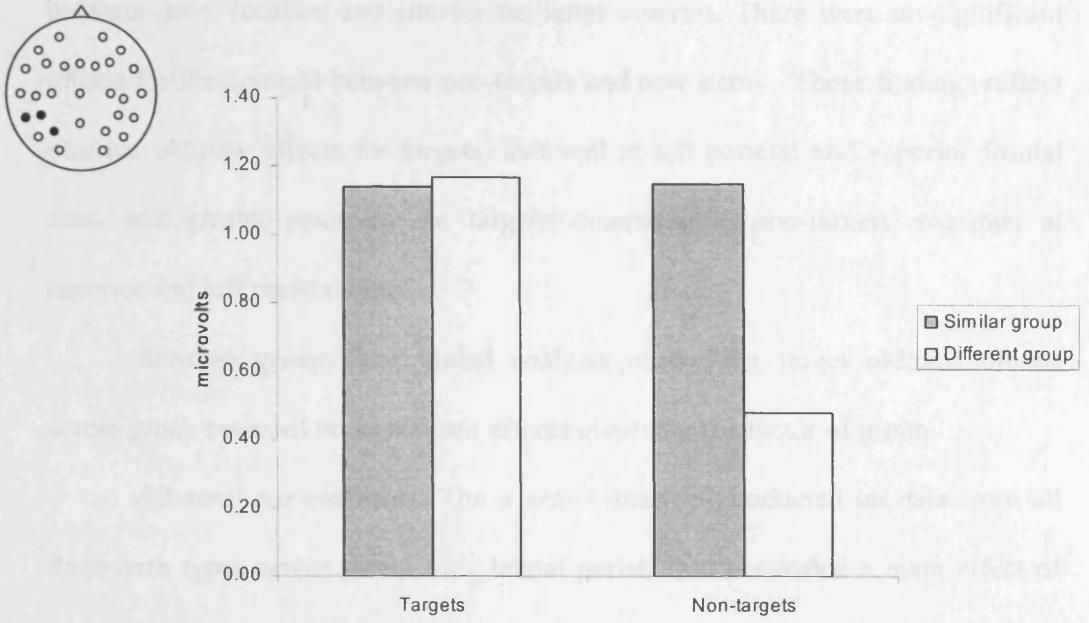

Figure 7.6.
Exp. 4 – Mean amplitudes (μV) of target (left) and non-target (right) old/new effects for the similar group (grey) and the different group (white) over the 300-500 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

hemisphere, location and site. The non-target old/new contrast gave rise to an item x hemisphere interaction and the contrast between targets and non-targets revealed a main effect of item.. For targets, these findings reflect generally greater positivity compared to non-targets and a positive old/new effect maximal at the left superior parietal site. For non-targets, these findings indicate old/new effects which are positive-going over the left hemisphere, but negative-going over the right hemisphere. However, subsidiary analyses revealed that these non-target old/new effects did not reach significance over either hemisphere.

Different group: The global analysis revealed a number of significant item effects, including a main effect, as well as interactions with site, and with hemisphere and location. The same pattern of effects was also evident for both the target/non-target contrast and the target old/new contrast, along with an interaction

between item, location and site for the latter contrast. There were no significant effects for the contrast between non-targets and new items. These findings reflect positive old/new effects for targets, maximal at left parietal and superior frontal sites, and greater positivity for targets, compared to non-targets, maximal at superior and left parietal sites.

Between group: The global analysis contrasting target old/new effects across group revealed no significant effects involving the factor of group.

Bilateral parietal sites: The *a priori* analysis conducted on data from all three item types across group over lateral parietal sites revealed a main effect of item [$F(2.0,59.0) = 11.35$, $p < 0.001$] along with interactions between item and hemisphere [$F(1.6,47.8) = 5.77$, $p < 0.01$] item and site [$F(2.7,80.1) = 5.65$, $p < 0.005$] and item, hemisphere and site [$F(3.0,90.6) = 3.00$, $p < 0.05$] The same pattern of effects were revealed for the contrast between targets and new items: item [$F(1,30) = 17.20$, $p < 0.001$] item x hemisphere [$F(1,30) = 7.42$, $p = 0.01$] item x site [$F(1.4,40.6) = 9.73$, $p = 0.001$] item x hemisphere x site [$F(1.5,44.2) = 4.45$, $p < 0.05$] The non-target old/new contrast across group revealed interactions between item and hemisphere [$F(1,30) = 6.57$, $p < 0.05$] and between group, item and site [$F(1.4,42.8) = 3.40$, $p < 0.05$] Subsidiary analyses found, for the similar group, an item x hemisphere interaction [$F(1,15) = 5.20$, $p < 0.05$] as well as an item x site interaction [$F(1.2,18.1) = 5.40$, $p < 0.05$] but no significant effects for the different condition. For the target/non-target contrast across group, there was a main effect of item [$F(1,30) = 17.68$, $p < 0.001$] and an item x site interaction [$F(1.5,45.9) = 4.34$, $p < 0.05$] For targets, these findings reflect, across group, positive-going old/new effects which are greater over the left- than the right

hemisphere and maximal at the left superior parietal site, and greater positivity than for non-targets, maximally over mid-lateral parietal sites. For non-targets, these findings indicate reliable old/new effects for the similar group only which are positive-going over inferior, mid-lateral and left parietal sites, but negative-going over superior and right parietal sites (see figure 7.7).

900-1100 msec

Similar group: ANOVA revealed an item x hemisphere interaction. The same effect was evident for the old/new contrasts for both non-targets and targets, along with an item x location x site interaction for targets. There were no significant item effects for the target/non-target contrast. These findings reflect reliable positive-going old/new effects for both types of old item, confined to the

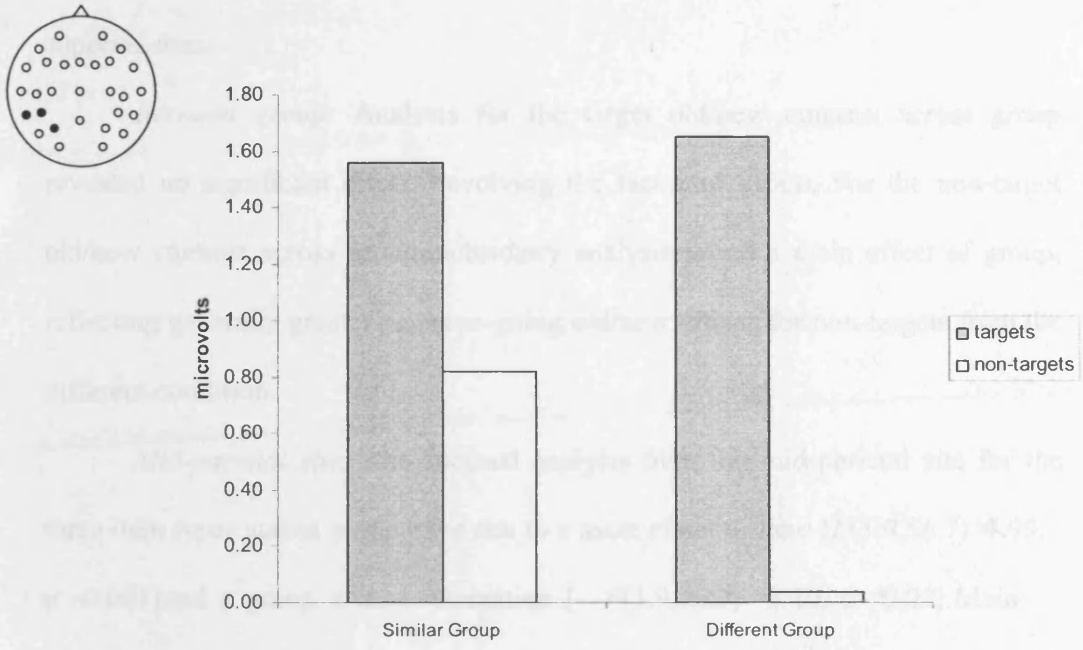

Figure 7.7.
Exp. 4 – Mean amplitudes (μV) of target and non-target old/new effects for the similar group (left) and the different group (right) over the 500-800 msec latency region. The mean amplitudes are collapsed across the three left parietal sites as indicated.

left hemisphere for non-targets and maximal at the left superior parietal site for targets, and small negative-going old/new effects for targets over right temporal and right inferior frontal sites.

Different group: Global analysis revealed a main effect of item and an item x hemisphere x location interaction. The latter interaction was also evident for the target old/new contrast as well as for the contrast between targets and non-targets. The non-target old/new contrast gave rise to a main effect of item, as well as interactions between item and location, and between item and site. For targets, these findings reflect old/new effects which are positive-going at frontal and left parietal sites, but negative-going at temporal and right parietal sites, and greater positivity, compared to non-targets, maximally at parietal sites over the left hemisphere and at frontal sites over the right hemisphere. For non-targets, these findings reflect negative-going old/new effects, maximal over temporal and superior sites.

Between group: Analysis for the target old/new contrast across group revealed no significant effects involving the factor of group. For the non-target old/new contrast across group, subsidiary analysis found a main effect of group, reflecting generally greater negative-going old/new effects for non-targets from the different condition.

Mid-parietal site: The focused analysis over the mid-parietal site for the three item types across group gave rise to a main effect of item [$F(1.9,56.7) = 7.99$, $p = 0.001$]and a group x item interaction [$F(1.9,56.7) = 3.40$, $p < 0.05$] Main effects of item were found for the contrast between targets and new items [$F(1,30) = 5.97$, $p < 0.05$] reflecting nega tive-going old/new effects for targets. Although

there was no interaction with group for this latter contrast, simple effects suggest that this target negativity was, in fact, confined to the different group (similar group: $F < 0.32$; different group: $F(1,30) = 5.97$, $p < 0.05$]. The contrast between non-targets and new items gave rise to a main effect of item [$F(1,30) = 13.33$, $p = 0.005$] and an interaction between group and item [$F(1,30) = 5.72$, $p < 0.05$]. Subsidiary analyses revealed no significant item effects for non-targets from the similar group, but a main effect of item [$F(1,15) = 20.58$, $p < 0.001$] for non-targets from the different group. There were no significant effects for the contrast between targets and non-targets. These findings reflect negative-going old/new effects at the mid-parietal site for targets and non-targets from the different group only (see Figure 7.8).

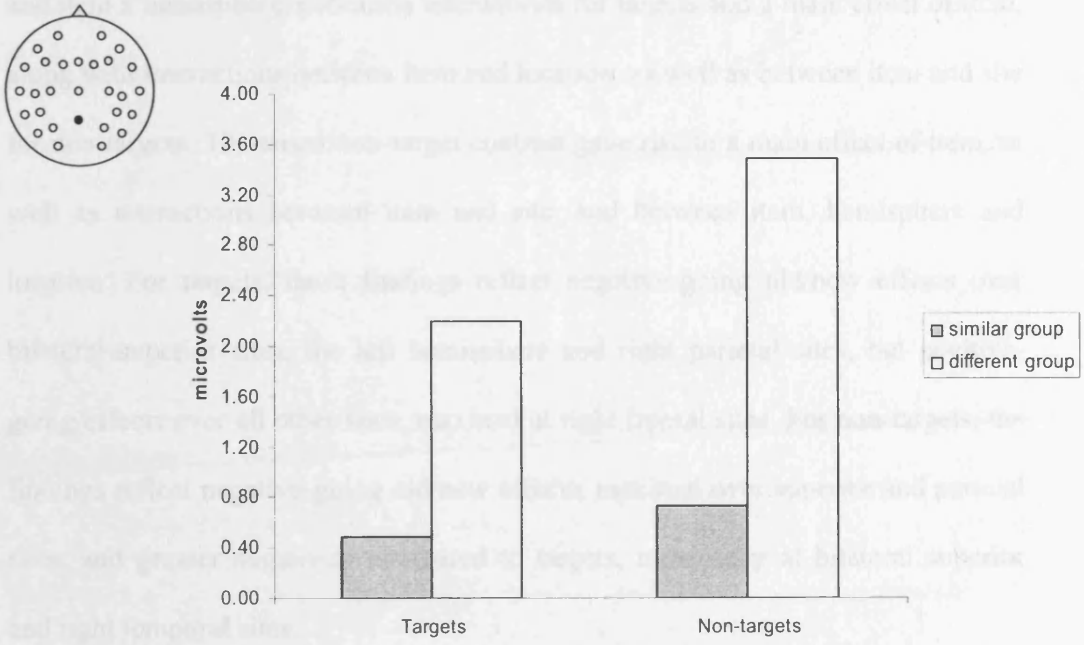

Figure 7.8.
Exp. 4 – Mean amplitudes (μV), at the mid-parietal site as indicated, of target (left) and non-target (right) old/new effects for the similar group (grey) and the different group (white) over the 900-1100 msec latency region.

1100-1400 msec

Similar group: The global analysis revealed an item x location x site interaction, evident also for the target and non-target old/new contrast, alongside an item x site interaction for the non-target old/new contrast. The contrast between targets and non-targets revealed no significant item effects. These findings reflect positive-going old/new effects over most sites for targets and non-targets, maximal over mid-lateral frontal sites for targets, but negative-going old/new effects at superior temporal/parietal and mid-lateral parietal sites for targets, and at superior temporal/parietal sites for non-targets.

Different group: ANOVA revealed a number of significant effects involving the factor of item, including a main effect, and interactions with location, with site, and with hemisphere and location. Old/new contrasts revealed item x site and item x hemisphere x location interactions for targets and a main effect of item, along with interactions between item and location, as well as between item and site for non-targets. The target/non-target contrast gave rise to a main effect of item, as well as interactions between item and site, and between item, hemisphere and location. For targets, these findings reflect negative-going old/new effects over bilateral superior sites, the left hemisphere and right parietal sites, but positive-going effects over all other sites, maximal at right frontal sites. For non-targets, the findings reflect negative-going old/new effects, maximal over superior and parietal sites, and greater negativity compared to targets, maximally at bilateral superior and right temporal sites.

Between group: The analysis contrasting target old/new effects revealed no significant effects involving the factor of group. For non-targets, the analysis

revealed a main effect of group [F (1,30) =5.59, p <0.05] and a group x site interaction [F(1.2,35.2) =4.70, p <0.05] re flecting generally greater negative-going old/new effects for non-targets from the different group, a difference which is maximal at superior sites.

Mid-parietal site: The focused analysis over the mid-parietal site for the three item types across group gave rise to a main effect of item [F(2.0,59.1) = 18.98, p <0.001] and a group x item interaction [F(2.0,59.1) =3.41, p <0.05] Main effects of item were found for the contrasts between targets and new items [F(1,30) =18.19, p <0.001] and between non-targets and new items [F(1,30) = 35.10, p <0.001] The non-target old/new contra st also revealed an interaction between group and item [F(1,30) =6.36, p <0.05] Subsidiary analyses revealed significant main effects of item for non-targets from the similar group [F(1,15) = 6.26, p <0.05] and for non-targets from the different group [F(1,15) =33.15, p < 0.001] There were no significant effects fo r the contrast between targets and non-targets. These findings reflect negative-going old/new effects at the mid-parietal site for targets and non-targets, although this negativity was significantly greater for non-targets from the different group compared to those from the similar group (see Figure 7.9).

1400-1900 msec

Similar group: ANOVA revealed a number of significant effects involving the factor of item, including interactions with hemisphere, with hemisphere and location, and with location and site. Target and non-target old new contrasts gave rise to main effects of item, as well as interactions between item and hemisphere, and between item, location and site. An item x location interaction was revealed for

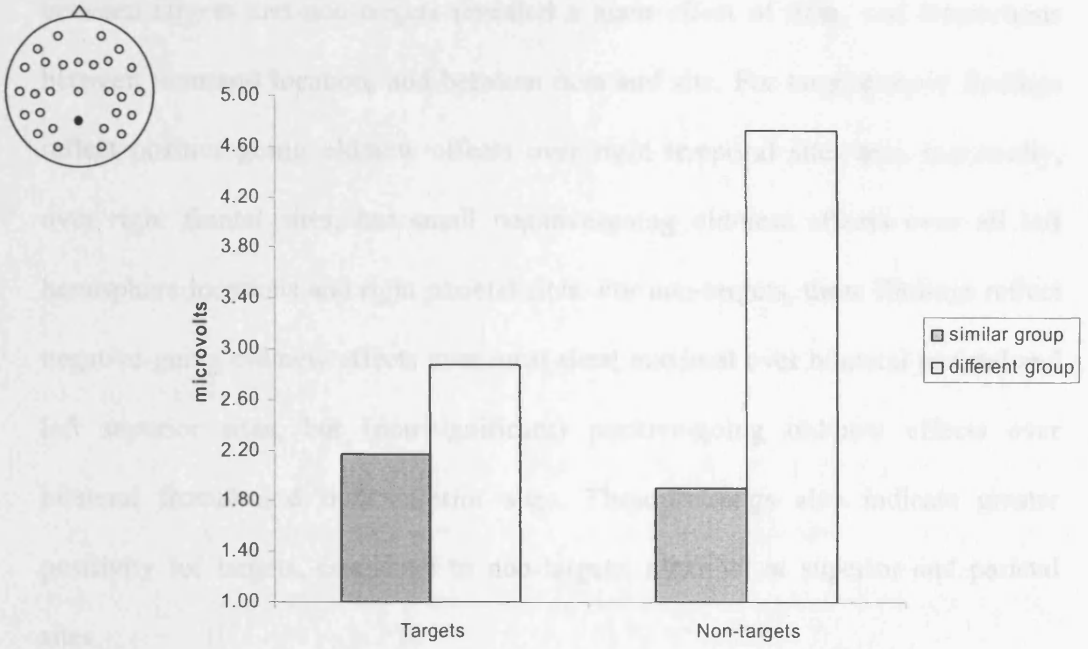

Figure 7.9.
Exp. 4 – Mean amplitudes (μV), at the mid-parietal site as indicated, of target (left) and non-target (right) old/new effects for the similar group (grey) and the different group (white) over the 1100-1400 msec latency region.

the contrast between targets and non-targets. These findings reflect mainly positive-going old/new effects for targets and non-targets, maximal over right hemisphere sites and bilateral superior parietal sites for targets, and maximal at right frontal sites for non-targets, but small negative-going old/new effects at superior parietal sites for targets, and at bilateral superior and left frontal/temporal sites for non-targets. These findings also indicate greater positivity for targets, compared to non-targets, maximally over frontal sites.

Different group: Global analysis gave rise to a number of significant item effects, including interactions with location, with site, with hemisphere and location, and with hemisphere and site. Old/new contrasts revealed item x location and item x hemisphere x location interactions for targets, and item x location, item x site and item x hemisphere x site interactions for non-targets. The contrast

between targets and non-targets revealed a main effect of item, and interactions between item and location, and between item and site. For targets, these findings reflect positive-going old/new effects over right temporal sites and, maximally, over right frontal sites, but small negative-going old/new effects over all left hemisphere locations and right parietal sites. For non-targets, these findings reflect negative-going old/new effects over most sites, maximal over bilateral parietal and left superior sites, but (non-significant) positive-going old/new effects over bilateral frontal and right inferior sites. These findings also indicate greater positivity for targets, compared to non-targets, maximal at superior and parietal sites.

Between condition: The analysis contrasting target old/new effects revealed no significant effects involving the factor of group. For non-targets, ANOVA revealed a group x location interaction [$F(1.2,36.8) = 5.65$, $p < 0.05$] reflecting greater negative-going old/new effects for non-targets from the different condition, a difference that is maximal at parietal sites.

Mid-parietal site: The focused analysis conducted on data from the mid-parietal site for the three item types across group revealed a main effect of item [$F(2.0,58.8) = 17.52$, $p < 0.001$]and a group x item interaction [$F(2.0,58.8) = 4.48$, $p < 0.05$] Main effects of item were found for the contrasts between targets and new items [$F(1,30) = 12.72$, $p = 0.001$] between targets and non-targets [$F(1,30) = 6.35$, $p < 0.05$]and between non- targets and new items [$F(1,30) = 32.43$, $p < 0.001$] For the non-target old/new contrast, there was also an interaction between group and item [$F(1,30) = 7.93$, $p < 0.01$] Subsidiary an alyses revealed significant main effects of item for non-targets from the similar group [$F(1,15) = 5.78$, $p <$

0.05] and for non-targets from the different group [$F(1,15) = 28.23$, $p < 0.001$] These findings reflect, across group, negative-going old/new effects at the mid-parietal site for targets and non-targets, although this negativity was significantly greater for non-targets from the different group compared to those from the similar group, and greater negativity for non-targets compared to targets (see Figure 7.10).

Topographic analyses

First, ANOVAs were conducted to contrast the scalp topography of non-target old/new effects across group. These ANOVAs employed the factors of group and site and were conducted for the latency regions within which significant group by scalp location interactions were revealed by the magnitude analyses directly contrasting old/new differences. However, for each of these latency regions (300-500, 1100-1400 and 1400-1900 msec) ANOVA failed to give rise to interactions

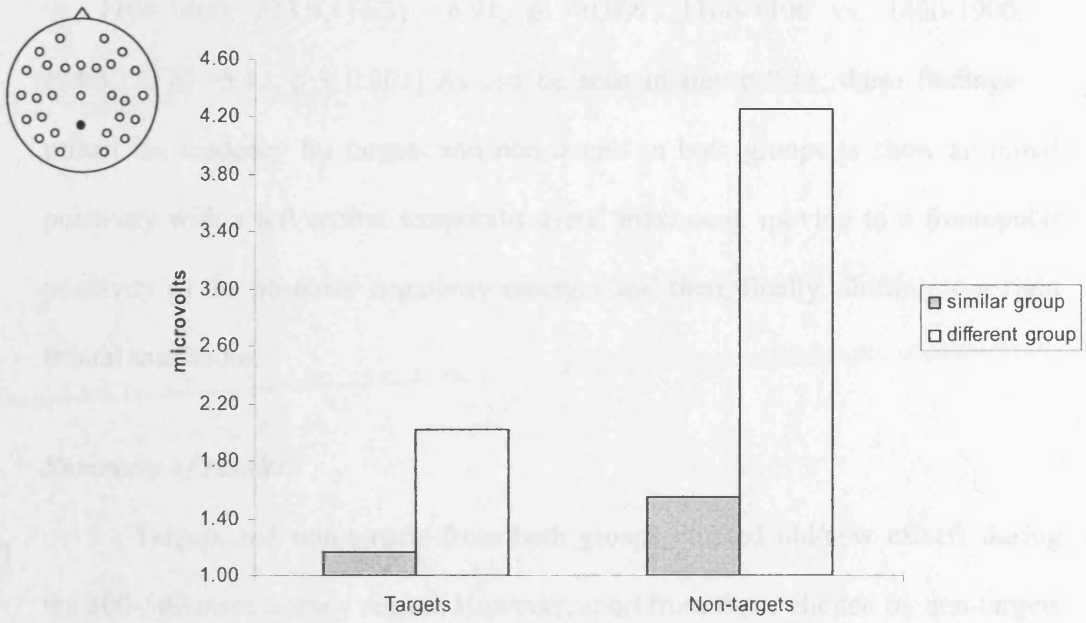

Figure 7.10.
Exp. 4 – Mean amplitudes (μV), at the mid-parietal site as indicated, of target (left) and non-target (right) old/new effects for the similar group (grey) and the different group (white) over the 1400-1900 msec latency region.

between group and site, indicating that the scalp distribution of non-target old/new effects did not differ according to group. ANOVA was then conducted to contrast reliable old/new effects for both groups as a function of item type (target/non-target) in the four latency regions (300-500, 900-1100, 1100-1400 and 1400-1900 msec) for which the magnitude analyses indicated differences in the distribution of target and non-target old/new effects. This latter analysis employed the factors of group, item type, latency region and electrode site, and gave rise to a latency region x site interaction [$F(5.5,165.9) = 6.97$, $p < 0.001$] As there were no additional qualifying interactions, this indicated that, across group and item type, changes in the scalp distribution of old/new effects varied across time. In order to determine when these changes occurred, subsidiary analyses were conducted for each pair of consecutive latency regions – each of these revealed interactions between latency region and site [300-500 vs. 900-1100: $F(3.5,106.0) = 5.94$, $p < 0.001$; 900-1100 vs. 1100-1400: $F(3.9,116.3) = 6.91$, $p < 0.001$; 1100-1400 vs. 1400-1900: $F(4.5,133.8) = 5.13$, $p < 0.001$] As can be seen in figure 7.11, these findings reflect the tendency for targets and non-targets in both groups to show an initial positivity with a left/central temporal/parietal maximum, moving to a frontopolar positivity as the posterior negativity emerges and then, finally, shifting to a right frontal maximum.

Summary of results

Targets and non-targets from both groups elicited old/new effects during the 300-500 msec latency region. However, apart from those elicited by non-targets from the different group, these early effects were more consistent with the development of a left parietal, rather than a mid-frontal, old/new effect (although

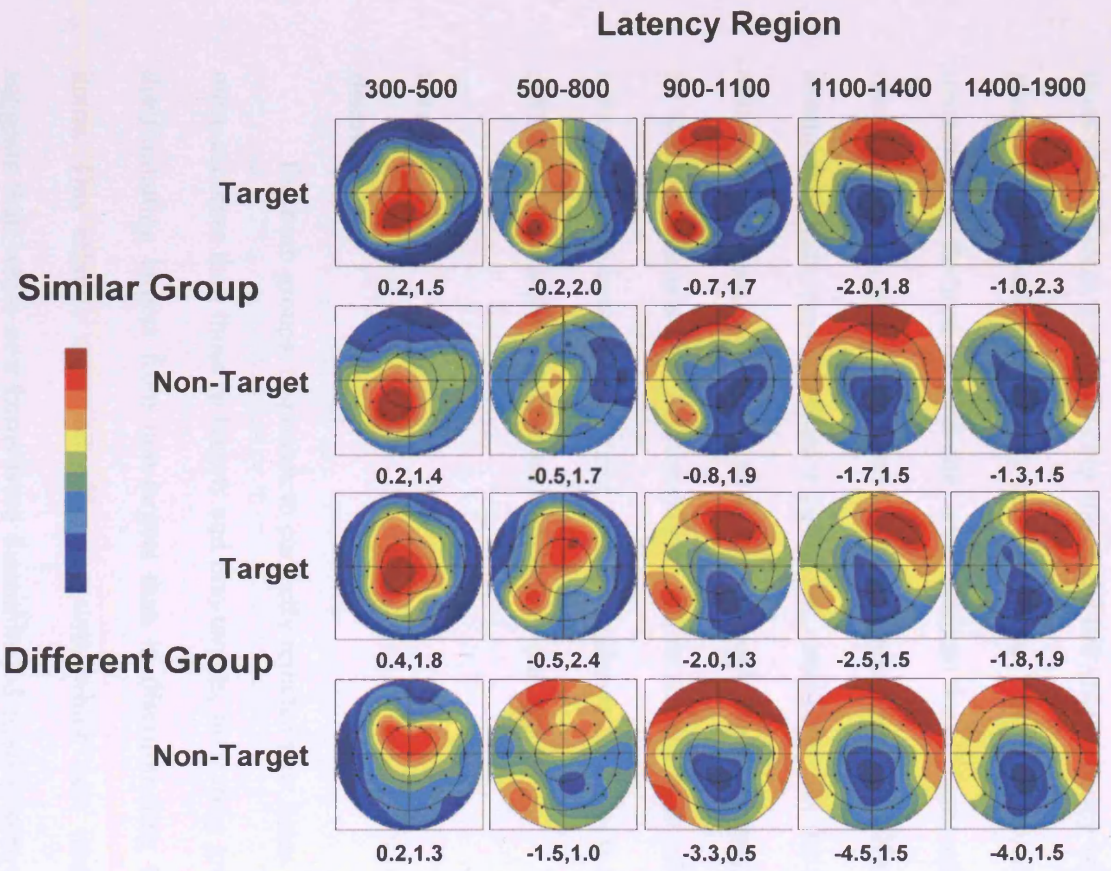

Figure 7.11.
Exp. 4 – Topographic maps of target and non-target old/new effects in the similar group and the different group for all latency regions as indicated. The paired values below each map indicate the voltage ranges (microvolts) of the differences between the two types of item (i.e., old-new) and can be interpreted with reference to the bar presented on the far left of the figure.

there was no reliable difference found for the scalp distribution of non-target old/new effects between the two groups). A left parietal effect was also evident for targets from both groups, as well as for non-targets from the similar group, during the 500-800 msec latency region. This latter effect was not elicited by non-targets from the different group. During the 900-1100 msec latency region, a negative-going old/new effect emerged for all items. This negativity was distributed maximally at the mid-parietal site, was sustained for all items until the end of the recording epoch, and was largest for non-targets from the different group. From around 900 msec post-stimulus, a positivity, consistent with the later right frontal old/new effect, was elicited by all items, although, for both groups, this tended to be larger for targets than for non-targets. While the scalp distribution of old/new effects differed across time, there was no evidence to suggest that these effects differed qualitatively as a function of group or item type.

Discussion

Behaviour

For both groups, responses to correctly rejected new items were quicker and more accurate than those to targets and non-targets, indicating greater difficulty in discriminating targets from non-targets than in discriminating targets from new items. This relative ease and efficiency with which new items were rejected suggests that, while new items were discriminated from targets on the basis of a lack of familiarity, given that targets and non-targets should be equally familiar, discrimination of these items required further information to differentiate their sources. Furthermore, the low false alarm rate for new items and high target accuracy indicate that successful target recollection provided the basis for accurate

responding to targets in this experiment. Responses to non-targets, however, were both slower and less accurate than those to targets, indicating greater difficulty and less confidence in identifying non-targets. Alongside the higher false alarm rate for non-targets in this experiment, compared to that found in Experiments 1-3 of this thesis, these behavioural findings no doubt reflect greater difficulty in discriminating non-targets from targets due to the increased similarity between target and non-target study contexts. As alluded to in the introduction, given the statistically equivalent accuracy levels for non-targets from the two groups, it would seem that the cognitive operations engaged by the visualisation task during study engendered sufficient overlap in target and non-target contexts to produce this increase in exclusion errors. Nevertheless, it is surprising that no significant behavioural differences were found between the two groups given that there was greater overlapping contextual information between targets and non-targets in the similar group. Therefore, in contrast to the ERP findings discussed below, these results provide no evidence of differential processing of non-targets as a function of group and, so, do not indicate whether or not the degree of similarity between target and non-target study contexts modulates non-target recollection.

ERPs

As expected, during the 500-800 msec latency region, correctly identified targets elicited a left parietal old/new ERP effect which, alongside the behavioural findings discussed above, indicate that the recollection of targets provided the basis for accurate responding to these items in this experiment. Furthermore, for the similar group only, correctly rejected non-targets also elicited a left parietal old/new ERP effect during the same latency region – for the different group, non-

targets failed to elicit this effect. These findings were predicted *a priori* and provide support for the proposal that the degree of similarity between target and non-target study contexts will modulate non-target recollection. More specifically, for the similar group, it would seem that, as there was greater overlapping contextual information between targets and non-targets engendered during the study phase, attempts to selectively retrieve target source inevitably gave rise to the recollection of non-targets. For the different group, however, as target and non-target study contexts were more distinct, a retrieval strategy, allowing the exclusive retrieval of target source, could be more successfully adopted. This account of the data may also explain why there have been inconsistent reports of left parietal old/new effects for non-targets in previous studies employing the exclusion task. As reviewed in the introduction, ERP studies reporting left parietal old/new effects for correctly rejected non-targets also employed study tasks that would have led to a considerable overlap in the contextual information associated with targets and non-targets (e.g., Cycowicz *et al.*, 2001; 2003; Wilding & Rugg, 1997; Wilding & Sharpe, 2004). In contrast, those studies reporting an absence of left parietal effects for non-targets employed study tasks that would have engendered distinct source information for targets (e.g., Dywan *et al*, 2002; 1998; 2001; Herron & Rugg, 2003a; 2003b). Together, these findings indicate that, while some measure of control may be exerted over what events are to be recollected, this will be facilitated when the relevant contextual information is sufficiently distinct.

Surprisingly, left parietal old/new effects were also found during the 300-500 msec latency region. These early effects revealed the same dissociative pattern between the two groups as evidenced during the 500-800 msec latency region –

although targets from both groups elicited left parietal effects during the 300-500 msec latency region, these were evident for non-targets from the similar group only. These findings suggest that early mnemonic processing is sensitive to particular aspects of the study context and, therefore, it would seem that recollection can be initiated earlier than had been assumed on the basis of previous studies. That memory for different types of information may revive at different times is consistent with the theoretical perspective of the source monitoring framework (Johnson *et al.*, 1993) and is a view which has been empirically supported (e.g., Johnson *et al.*, 1994). So, it could be that the particular paradigm employed in the present experiment led to the relatively rapid retrieval of specific contextual details associated with targets and non-targets from the similar group as well as with targets from the different group. However, given that the mid-frontal old/new effect, thought to reflect processes of familiarity, is usually found during the same 300-500 msec latency region, this account of the data does not sit well with dual-process models which assume processes of familiarity to occur at an earlier time point than those of recollection. Nevertheless, in the present experiment, while mid-frontal old/new effects were elicited by targets from both groups, these were elicited by non-targets from the different group only. In conjunction with inconsistent findings of mid-frontal effects reported in Experiments 1-3 of this thesis, as well as in other recent ERP studies reviewed in the previous experimental chapter (Schloerscheidt & Rugg, 2004; Tsivilis *et al.*, 2001; Yovel & Paller, 2004), there is growing uncertainty as to whether processes of familiarity are, in fact, indexed by this early ERP effect. If, indeed, familiarity processing occurs at an earlier time point as has previously been suggested (Brown

& Bashir, 2002; Brown & Xiang, 1998), the notion that processes of recollection may also occur at an earlier time point than has previously been assumed would, in this case, not be incompatible with dual-process models. Nevertheless, caution is required in interpreting such early apparent left parietal effects found in the present experiment until such effects have been replicated.

A further dissociation between the two groups was apparent from the differential appearance of late negative-going effects over the mid-parietal site. These effects were elicited by all studied items, although they occurred earlier (i.e., during the 900-1100 msec latency region) for both targets and non-targets from the different condition and, from 1100 msec post-stimulus until the end of the recording epoch, were significantly greater for non-targets from the different group than for any other studied item. As detailed in the previous experimental chapter, there have been a number of suggestions relating to the functional role of this ERP effect during memory retrieval. The findings of equivalent negative-going old/new effects for all familiar items in Experiment 3 of this thesis were most consistent with the proposal that this negativity reflects processes related to the search for the conjunction of item and associated contextual information (Johansson & Mecklinger, 2003). However, the discrepant findings from the present experiment do not concur with this proposal as it would be difficult to explain why processes relating to this type of search should engage non-targets from the different group to a greater extent than any other familiar item. Although it could be argued that the failure to recollect non-targets from the different group led to greater efforts to search for the combination of item and source information, this proposal does not account for why a greater negative old/new effect was also not elicited by non-

recollected non-targets from the deep condition compared to other recollected familiar items in Experiment 3. In fact, the pattern of negative-going old/new effects found in the present experiment would seem to correlate with the amount of contextual information associated with each familiar item type that is *irrelevant* to the task demands. This observation, however, presupposes that contextual information was retrieved for targets and non-targets from both groups and may be problematic for the above account of why non-targets from the different group failed to elicit a left parietal old/new effect. It was suggested that, for the different group, as target and non-target study contexts were relatively distinct, the adoption of a specific retrieval orientation allowed the *exclusive* retrieval of target source. In contrast to this view, however, findings from Experiments 1 and 2 of late left parietal effects for non-targets when these same items failed to elicit an earlier effect suggested that the employment of a specific retrieval orientation served to delay, rather than preclude, the recollection of non-targets. This proposal would also be compatible with the observation in the present experiment that the elicitation of late left parietal effects for non-targets from the different group (and, perhaps, even earlier left parietal effects too) may have been obscured by the overlapping negativity during the same latency region(s).

One intriguing possibility is that the mid-parietal negativity reflects processes acting upon a mismatch between the targeted memory representation (i.e., via an adopted 'retrieval orientation') and the (irrelevant) contextual details that are actually retrieved (cf. Anderson & Bjork, 1994). Such irrelevant contextual details are likely to have been retrieved for targets and non-targets from both groups, albeit of different types and to varying degrees. For the similar group in the

present experiment, given the response-time constraint and the fact that the second study task was identical for targets and non-targets, it is likely that search operations were directed towards retrieving contextual information associated with the visualisation task as this information was necessary for the target/non-target discrimination. Therefore, the delayed retrieval of irrelevant contextual details would have included those associated with the second study task (indoor/outdoor or pleasantness rating) for both targets and non-targets from the similar group. For the different group, assuming that a retrieval search was directed towards distinct contextual information associated with the second study task allocated to targets (indoor/outdoor or pleasantness rating), irrelevant details for targets would have included contextual information associated with the visualisation task. For non-targets from the same group, however, such irrelevant information would have included contextual details associated with both the visualisation task as well as with the second study task allocated to non-targets. It can, therefore, be seen that processes acting upon a mismatch between the target memory representation and retrieved irrelevant memories are likely to have been engaged to the greatest extent for non-targets from the different group – such processing would have involved a greater number of contextual details and is, perhaps, reflected in the greater negativity elicited by these items. It is also possible that differences in the onset of the late negativity between the two groups may reflect differences in the delayed revival of mismatched contextual details according to the type of information with which these details were associated. Whether such processes tentatively proposed to be reflected by the late negativity act to suppress irrelevant information or to simply register a mismatch, it would seem that these may act in concert with the

adoption of a specific retrieval orientation to bias initial retrieval, and subsequent attention, towards relevant memories amongst competing alternatives.

Conclusion

Experiment 4 investigated whether the ERP correlates of recollection would differ according to the degree of similarity between target and non-target study contexts. As predicted, for the similar group only, correctly rejected non-targets elicited a left parietal old/new ERP effect. In this case, as there was greater overlapping contextual information between targets and non-targets engendered during the study phase, attempts to retrieve target source gave rise to the recollection of non-targets. For the different group, however, non-targets failed to elicit a left parietal old/new effect. As target and non-target study contexts were partially distinct, here it seemed a retrieval strategy, allowing exclusive recollection of target source, was more successfully adopted. Surprisingly, between 300-500 msec, left parietal old/new effects were elicited by targets for both groups and by non-targets for the similar group only, suggesting that early mnemonic processing may be sensitive to differential aspects of the study context. During the same latency region, mid-frontal old/new effects were elicited by targets from both groups and by non-targets from the different group only, adding to growing uncertainty as to whether this early ERP effect does, in fact, index processes of familiarity. Finally, findings of a late posterior negativity for all familiar items, but which was greater for non-targets from the different group, suggested that this effect may be sensitive to the retrieval of irrelevant memories, and may have attenuated a possible left parietal old/new effect for non-targets from the different group. It was tentatively suggested that, while the adoption of a specific retrieval

orientation may lead to the delay, and not necessarily the exclusion, of irrelevant memories, processes acting upon a mismatch between a targeted memory representation and irrelevant contextual details may help to bias attention towards those that are relevant.

CHAPTER 8

General Discussion

The experiments presented in this thesis employed scalp-recorded ERPs to explore the strategic control of recollection in a recognition exclusion task. After summarising the principal findings for each experimental chapter, there will be a broad discussion of some basic experimental findings in relation to existing theories and research relating to recognition memory. This discussion will then focus on the implications of the principal findings relating to the control of recollection by, initially, considering how these contribute to our understanding of the functional significance of the left parietal old/new ERP effect. Reciprocally, the pattern of left parietal old/new effects reported in this thesis will be examined in order to address what mechanisms might account for selective retrieval processing. While other results relating to the behavioural and ERP data have been discussed in depth within their respective experimental chapters, some of these will be re-examined when appropriate. Finally, objectives for future research will be identified.

Summary of principal findings

Experiments 1 and 2: The employment of different retrieval strategies in an exclusion task and their influence on ERP correlates of recollection.

Experiment 1 explored whether the ERP correlates of recollection would differ depending on the retrieval strategies employed in two versions of an exclusion task. For the 'picture condition', non-targets were pictures and, for the 'word condition', non-targets were words. In both conditions, targets and test cues

were words. Study tasks were selected to elicit good memory for non-targets and poor memory for targets. For the word condition, a left parietal old/new effect was elicited by non-targets, but not by targets, suggesting that, as there was minimal source information available for targets, the discrimination of these items was based on non-target recollection. In contrast, for the picture condition, there was no evidence that recollection occurred for either targets or non-targets as there were no left parietal old/new effects elicited in this condition. Instead, at a relatively early time-point, targets and non-targets engaged functionally distinct sets of processes which would seem to have provided the basis for their discrimination to be executed both quickly and heuristically.

Experiment 2 explored whether targets and non-targets would be differentially discriminated according to whether non-targets were pictures or words when memory for targets was good. The design for Experiment 2 was identical to that employed in Experiment 1 except that a pleasantness judgement task was employed at study to elicit good memory for targets. For both conditions, a left parietal old/new effect was elicited by targets only – these findings suggested that, when memory for targets is good, a retrieval strategy can be adopted that allows processing resources to be selectively devoted to target recollection. However, the finding of late left parietal old/new effects for non-targets, when these same items failed to elicit an earlier effect, indicated that the retrieval strategy adopted served to delay, rather than preclude, non-target recollection.

Experiment 3: Investigating the functional significance of the early P2 modulation.

Experiment 3 investigated findings from Experiment 1 that ERPs to targets were more positive than those to both non-targets and new items at a latency of 100-300 msec post-stimulus. As this P2 modulation was observed for targets in Experiment 1, but not in Experiment 2, it was hypothesised that it may be the shallow-encoding of targets, in contrast to the deep-encoding of non-targets, giving rise to this early modulation. Experiment 3 employed a hybrid of the designs previously used, taking the blocks from Experiments 1 and 2 corresponding to the word condition to be used in a within-subject design. This design represented a replication of that employed by Herron and Rugg (2003a) but with target encoding manipulated within, rather than between, subjects. In the 'shallow' condition, targets were shallowly encoded and, in the 'deep' condition, targets were deeply encoded – in both conditions non-targets were deeply encoded. As ERPs to targets did not significantly differ from those to non-targets or new items in either the shallow condition or the deep condition during the 100-300 msec latency region, the experimental hypothesis was not supported. However, as found previously, a left parietal old/new effect was elicited by correctly identified non-targets only when targets had been shallowly encoded. These findings indicated that there are situations in which the recollection of non-targets may be under strategic control. Accordingly, when there is poor memory for targets, it would seem necessary to retrieve non-target source information in order to reject these items. However, when there is good memory for targets, the adoption of a specific 'retrieval

orientation' may allow test cues to selectively probe memory for targets at the expense of non-target recollection.

Experiment 4: Recall-to-reject and contextual discrimination: The influence of contextual distinctiveness on the control of recollection in exclusion tasks.

Experiment 4 investigated whether the successful adoption of a specific retrieval orientation, allowing the selective retrieval of target source information, is dependent upon the degree of similarity between target and non-target study contexts. For the 'similar group', target and non-target study tasks were identical and, for the 'different group', target and non-target study tasks were more distinct. For both groups, study tasks were chosen to elicit good memory for targets and non-targets. It was proposed that, with greater similarity between target and non-target study contexts, attempts to retrieve target source should, to some extent, give rise to the recollection of non-targets. Indeed, for the similar group only, correctly rejected non-targets elicited a left parietal old/new effect. It would seem that, with greater overlapping contextual information between targets and non-targets engendered during the study phase, it would not be possible to focus retrieval attempts exclusively on target source information. For the different group, however, as target and non-target study contexts were partially distinct, a retrieval strategy, that allowed exclusive recollection of targets, could be adopted more successfully. On the other hand, findings of a late posterior negativity for targets and non-targets from both groups, but which was greater for non-targets from the different group, suggested that this effect may be sensitive to the retrieval of *irrelevant* memories. Furthermore, this negativity may have attenuated a possible left parietal old/new effect for non-targets from the different group given that these

ERP effects, to some extent, overlapped both temporally and spatially. It was tentatively suggested that, while the adoption of a specific retrieval orientation may lead to the delay, and not necessarily the exclusion, of irrelevant memories, processes acting upon a mismatch between a targeted memory representation and irrelevant contextual details may help to bias attention towards those that are relevant to the task at hand.

General implications for models of recognition memory

The findings summarised above suggest that complex recognition tasks engage a flexible system that can modulate processes involved in recognition depending upon the type and quality of retrieved information as well as the strategies adopted by participants as required by the demands of the task. For all four experiments, the exclusion task required the endorsement of targets from a specified source (study list 2) and the rejection of all other items, including new items and non-targets from the alternative source (study list 1). It has been argued that, in the exclusion task, while targets may be correctly identified on the basis of familiarity and/or recollection, the correct rejection of non-targets necessarily requires the retrieval of their study source (Jacoby, 1991). One advantage in employing the exclusion task is that it allows an assessment of the extent to which old/new effects depend upon differential response categories. Given that correctly rejected non-targets and new items receive the same response, any differences in ERPs between these two item types must represent something other than differential response selection.

Following on from this, however, a caveat in the interpretation of contrasts involving non-targets arises because a correct response to these items can be made,

not only when they have been remembered, but also when they have been forgotten – i.e., when their familiarity levels are below criterion and retrieval of their study source fails. In Experiment 2 presented in this thesis, for example, deeply encoded targets in study list 2 may have engendered sufficient retroactive interference to render non-targets inaccessible at test (Herron & Rugg, 2003a). As study list 1 items, designated as non-targets, were, at no point, designated as targets in alternative conditions, there is no measure available to identify just how memorable non-targets were in each of the four experiments. Therefore, given that an unknown proportion of excluded non-targets will have little or no retrieval-related neural activity, the power to detect old/new effects will, generally, be greater for targets than for non-targets in exclusion tasks. One implication of this is that, when statistically equivalent left parietal old/new ERP effects are obtained for targets and non-targets, it cannot be conclusively claimed that recollection is, therefore, engaged to comparable extents. Furthermore, when left parietal old/new effects for targets are reliable but small, then the absence of reliable left parietal old/new effects for non-targets must be treated cautiously in terms of the proposed strategies under which non-targets are, apparently, not recollected. Nevertheless, the marked attenuation of left parietal old/new effects for non-targets across the different experiments and conditions in this thesis suggests that a high degree of control was indeed exerted over the information to be retrieved. This idea is also compatible with previous findings, such as those of Herron & Rugg (2003a), where the issue of non-target memorability was addressed after finding that there were no left parietal old/new effects for non-targets when targets had been deeply encoded (Experiment 1). In their follow-up behavioural study, participants were required, at

test, to exclude study list 2 items (previously targets) and to endorse study list 1 items (previously non-targets). In this follow-up study, mean accuracy levels for targets (i.e., items from study list 1) were 86% against a false alarm rate of 3% for new items. Therefore, it would seem highly unlikely that non-targets in Experiment 1 had been forgotten as a result of retroactive interference from deeply-encoded targets.

Finally, as addressed in Experiment 4 of this thesis, it would appear that there are factors other than level of target memorability that may have led to the selective retrieval of target source information. Findings from Experiment 4 indicated that the successful adoption of such a retrieval strategy could only occur when target and non-target study contexts were, to some extent, distinct. Aside from differences between target and non-target study tasks, the temporal segregation of target and non-target study lists in all four experiments is also likely to have played a role in distinguishing between these two item types at test. This raises the issue of the different sources of information upon which participants might have relied both within and across conditions. For example, as the non-target study list was always presented before the target study list, participants may have employed recency information to distinguish between targets and non-targets at test. Nevertheless, even if recency information had been employed, correctly identified targets and non-targets would still be expected to elicit left parietal old/new effects as has been found previously for old items presented in a task involving recency judgements (Tendolkar & Rugg, 1998). Furthermore, the exclusive retrieval of target source information has also been reported when targets and non-targets were presented intermixed in a single study list (Herron & Rugg,

2003b). Therefore, the use of recency information cannot explain the pattern findings presented in this thesis that suggest the use of a retrieval strategy permitting the exclusive recollection of targets.

While the discrimination of targets and non-targets requires the retrieval of specific episodic information, a correct old/new response can be made on the basis of the presence or absence of non-specific information, such as familiarity. In all four experiments presented in this thesis, the behavioural data suggests that participants were able to discriminate old from new items before they were able to discriminate targets from non-targets. Therefore, it would appear that many old items were initially recognised as being old prior to an attribution of source being made. This discrimination of old from new items may either have been made on the basis of early familiarity information, thought to be available prior to recollection (Mandler, 1980; Yonelinas & Jacoby, 1994), or may have been made on the basis of accruing undifferentiated recollection of non-diagnostic contextual details (Johnson *et al.*, 1993; Johnson *et al.*, 1994). The hypothesis that these items were initially recognised on the basis of familiarity is consistent with the view that both targets and non-targets elicit familiarity-based recognition in exclusion tasks (Jacoby, 1991). However, Experiments 1-4 demonstrated little evidence of familiarity-based recognition for non-targets as reflected by the early mid-frontal old/new ERP effect. In Experiments 1-2, an early mid-frontal old/new effect was evident for targets, but not for non-targets, in both the picture and word conditions. That non-targets were simply forgotten is not a plausible argument for their failure to elicit these early effects as non-targets from the word condition in Experiment 1 were apparently recollected as evidenced by left parietal old/new effects.

Furthermore, in Experiment 3, early old/new effects were not elicited by targets or non-targets in the shallow condition at mid-frontal sites during the 300-500 msec latency region, and these early effects did not occur at all for targets and non-targets in the deep condition. Finally, in Experiment 4, while mid-frontal old/new effects were elicited by targets from both groups, these were elicited by non-targets from the different group only. Alongside other inconsistent findings of mid-frontal effects in other recent ERP studies reviewed in Experiment 3 (Schloerscheidt & Rugg, 2004; Tsivilis *et al.*, 2001; Yovel & Paller, 2004), there seems to be growing uncertainty as to whether processes of familiarity are, in fact, indexed by this early ERP effect.

In contrast, findings from Experiments 1-4 are generally consistent with the view that the left parietal old/new effect indexes processes of recollection (see later sub-section, 'Implications of Principle Findings'). As reviewed in Chapter 3, evidence relating the left parietal old/new effect to recollection comes from a number of studies that have reported this effect to be sensitive to behavioural manipulations known to influence recollection. For example, this effect is enhanced when an item's source is correctly, rather than incorrectly, identified (e.g., Wilding, 2000; Wilding & Rugg, 1996), is larger for items accorded a 'remember', as opposed to a 'know', judgement (e.g., Duzel *et al.*, 1997; Smith, 1993; Trott *et al.*, 1999) and is sensitive to depth of processing manipulations (e.g., Paller *et al.*, 1995; Rugg *et al.*, 2000; Rugg *et al.*, 1998). Furthermore, the left parietal old/new effect has been found to be absent in neurological patients for whom recollection is selectively impaired (Duzel *et al.*, 2001; Tendolkar *et al.*, 1999). Very recently, however, Yonelinas and colleagues (2005) have pointed out

that there is a confound between items that are associated with recollection and those that are associated with high levels of recognition confidence as items eliciting correct source judgements tend to be associated with the latter. Therefore, as items that are accepted on the basis of familiarity may be associated with a wide range of recognition confidence, brain activity that is apparently associated with processes of recollection may, rather, be responding to increasing levels of familiarity-based recognition confidence. Although the link between processes of recollection and the left parietal old/new effect is very strong, it will, nevertheless, be important for future investigations of ERP correlates of recollection- and familiarity-based recognition to address this issue. For example, it will be important to demonstrate that patterns of neural activity associated with increases in familiarity-based recognition confidence are qualitatively distinct from those revealed by contrasts between responses associated with recollection-based recognition and highly confident responses associated with familiarity-based recognition. It will also be important to supplement objective measures of recollection and familiarity with subjective reports of what type of information is providing the basis of a response in recognition tasks. One advantage, in particular, of using the Remember / Know procedure in conjunction with objective measures is that measures of the retrieval of source information associated with a test item may include any contextual information from the study episode whereas objective measures (i.e., source tasks) may include only specified contextual information. In this way, the functional significance of ERP correlates of recollection may be further delineated.

Implications of principal findings

Functional significance of the left parietal effect

As mentioned above, the findings reported in this thesis have been generally consistent with the view that the left parietal old/new effect reflects processes of recollection. These effects were elicited by targets when they had been deeply encoded (Experiments 2 and 4) but not when they had been shallowly encoded (Experiment 1). As deeply-encoded items are more likely to have been accompanied by the retrieval of source information than those that have been shallowly encoded, these findings concur with the notion that the left parietal old/new effect is a neural correlate of recollection. Nevertheless, this pattern of results was not observed in Experiment 3 when depth of target encoding was manipulated within-subjects. In this latter experiment, both deeply- and shallowly-encoded targets failed to elicit reliable left parietal old/new effects during the 500-800 msec latency region. Instead, short-lived left parietal old/new effects were apparent for targets in both conditions between 500-650 msec post-stimulus. It seemed unlikely, though, that these effects would have reflected vivid recollection in both conditions as accuracy for shallowly-encoded targets was poor. It was argued that these short-lived effects reflected processes underlying the retrieval of partial or less specified aspects of source information (Johnson *et al.*, 1993). This interpretation was predicated on the basis of previous reports of successful source attributions that were based on the retrieval of partial source information (e.g., Dodson *et al.*, 1998) as well as the finding that the left parietal old/new effect may index the amount of information retrieved from episodic memory in a graded, rather than 'all-or-none', fashion (Wilding, 2000). However, as left parietal

old/new effects were elicited by non-targets in the shallow condition, but not in the deep condition, this suggested that the retrieval of partial or less specified aspects of target source information was not sufficient to permit a discrimination between targets and non-targets in the shallow condition. Furthermore, it was argued that, as there was a greater distinction between contextual information associated with targets and non-targets in the deep condition, only in this case could partial source information could be used as the basis for their successful discrimination. It must be noted, however, as will be discussed for non-targets below, that an alternative interpretation for these short-lived left parietal effects may be their attenuation by the spatially and temporally overlapping early component of the late posterior negativity.

In line with previous findings (Dywan *et al*, 2002; 1998; 2001; Herron & Rugg, 2003a; 2003b), correctly rejected non-targets did not always elicit left parietal old/new effects. The failure of non-targets to elicit these effects occurred when memory for targets was good and/or contextual information associated with targets and non-targets was sufficiently distinct – Experiments 1 (picture condition), 2 (picture and word conditions), 3 (deep condition) and 4 (different group). It has previously been argued that the left parietal old/new effect may be sensitive to the *task relevance* of retrieved information (Dywan *et al.*, 1998). For example, Herron & Rugg (2003a) suggested that the failure of non-targets to elicit left parietal effects may reflect, not the failure to retrieve non-target source, but, rather, the failure to allocate processing resources to this information. However, in light of their findings from another ERP study that employed the exclusion task, Herron and Rugg (2003b) proposed that the lack of left parietal effects for non-

targets can be more parsimoniously explained by the adoption of a retrieval orientation that allows test cues to be processed in a way that selectively probes for target recollection.

The idea that specific retrieval orientations can be maintained during recognition has been supported by investigations that have contrasted neural activity associated with the presentation of test cues across tasks that vary the nature of the memory representation being sought (for reviews, see Donaldson *et al.*, 2003; Wilding & Sharpe, 2003). These contrasts have been limited to 'new' test items so as to eliminate possible confounds with retrieval success. In the experiments presented in this thesis, however, such contrasts would not have been able to provide unequivocal evidence of the engagement of different retrieval orientations between conditions / groups. This is because the effects of retrieval orientation would have been confounded with those of retrieval effort given the differential accuracy and RT levels between conditions (Experiment 1 vs. Experiment 2; Experiment 3 – shallow condition vs. deep condition) or obscured by the use of different task types due to the counterbalancing methods employed (Experiment 4). Nevertheless, in ERP studies that have employed the exclusion task, evidence for task-specific retrieval processing in the absence of such confounds is accruing (Dzulkifli, Sharpe & Wilding, 2004; Dzulkifli & Wilding, 2005). As noted by Dzulkifli & Wilding (2005), however, it is uncertain whether the differences between ERPs elicited by new items reflect processes operating on, for example, the memory representations themselves in order to influence their accessibility or the retrieval cues such that they interact selectively with a specific class of memory representation. Therefore, it would seem that the data, so far, is

equivocal with regard to the mechanisms by which selective retrieval processing may occur, e.g., via non-inhibitory 'cue bias' or inhibitory 'target bias' (Anderson & Bjork, 1994) and, so, whether or not non-targets are indeed recollected. This issue will be discussed in more detail below.

Two pieces of evidence from the experiments presented in this thesis, however, suggest that non-target recollection may, indeed, have occurred. First, the finding of later-onsetting left parietal old/new effects for non-targets in Experiments 1 (picture condition) and 2 (picture and word conditions), when these same items failed to elicit an earlier effect, indicate that the retrieval strategy adopted served to delay, rather than preclude, the recollection of non-targets. Second, it was observed in Experiment 4 that negative old/new effects over the mid-parietal site were both earlier onsetting and greater in magnitude for non-targets from the different group compared to those from the similar group, while left parietal old/new effects were elicited by non-targets from the similar group only. As left parietal and late negative old/new effects overlap to some extent both temporally and spatially, the possible elicitation of left parietal effects for non-targets from the different group may well have been obscured. Nevertheless, without knowing what mechanism(s) may be responsible for the apparent control over non-target recollection, the data presented in this thesis is equivocal with regard to what extent the left parietal old/new effect may index the phenomenal experience of recollection and whether or not this effect is sensitive to the relevance of the information retrieved.

Mechanisms underlying selective retrieval processing

Two mechanisms in particular, 'cue bias' and 'target bias', detailed in Anderson and Bjork's (1994) taxonomy of inhibitory (and non-inhibitory) mechanisms in memory, have been proposed to account for the control over non-target recollection in exclusion tasks (Herron & Rugg, 2003a; 2003b). It was originally proposed that 'attentional suppression' might account for the absence of a left parietal old/new effect for non-targets when memory for targets was good (Herron & Rugg, 2003a). This mechanism was described by Anderson and Bjork (1994) as one of a class of memory inhibition target bias models in which retrieval is compared to the internal focus of attention on memory items. According to an attentional suppression account, while both target and non-target memories will initially be activated, attentional mechanisms will enhance target activations and, at the same time, deactivate non-target competitors, resulting in retrieval inhibition. In this way, target memories can be isolated from among a set of competing alternatives. Being an inhibitory model in the strong sense of its meaning, inhibition should occur at the level of the item's representation.

An alternative possibility is that the selective retrieval of target source at the expense of non-target recollection can be achieved via a non-inhibitory 'cue bias'. Essentially, this is equivalent to the adoption of a 'retrieval orientation' which is thought to optimise the processing of test items as cues for the selective retrieval of targeted memory representations. As indicated by Anderson and Bjork (1994) in their discussion of a 'context bias', retrieval will fail if the contextual representation specified for the memory search does not match that presented at study. It follows that, in an exclusion task, if the targeted memory representation

specifies contextual information associated specifically with the target study phase, non-targets will not be recollected. Furthermore, the successful adoption of such a mechanism is also assumed to depend upon contextual information associated with targets being sufficiently distinct from that associated with non-targets. Therefore, the finding in Experiment 4, that non-targets elicited a left parietal old/new effect when target and non-target study contexts were similar (similar group) but not when these were partially distinct (different group), is consistent with the idea that the adoption of a specific retrieval orientation may account for the apparent control over non-target recollection in this latter group.

In the same experiment, however, it was suggested that a negative old/new effect centred over the mid-parietal site may well have attenuated a possible left parietal old/new effect for non-targets in the different group. This was because these ERP effects partially overlapped both spatially and temporally for these items in particular. Although there have been a number of suggestions relating to the functional role of the late posterior negativity during memory retrieval, it is currently thought to index a combination of processes that are both response-locked and stimulus-locked (Johansson & Mecklinger, 2003). In general, this negativity has often been reported in ERP studies in which source judgements have been required and, in particular, the stimulus-locked component has been suggested to reflect processes related to the search for and/or maintenance of the conjunction of item and associated contextual information (Johansson & Mecklinger, 2003). Furthermore, a number of researchers have identified this late posterior negativity with the reinstatement of the original item in its associated context (e.g., Cycowicz *et al.*, 2001; Johansson, Sternberg, Lindgren & Rosen, 2002). Strikingly, the

finding that this negativity was elicited in Experiment 4 by targets and non-targets from both groups but was significantly greater for non-targets from the different group suggested that the magnitude of this effect correlated with the amount of contextual information associated with each item type that was *irrelevant* to the task demands. This observation led to the proposal that the mid-parietal negativity reflects processes acting upon a mismatch between the targeted memory representation (i.e., via an adopted 'retrieval orientation') and the (irrelevant) contextual details that are actually retrieved.

Together, the above observations suggest that non-target contextual details may actually have been retrieved in the different group and that the *partial* overlap between target and non-target study contexts in this group led to the failure of the adopted retrieval orientation to focus retrieval operations exclusively on target context. Furthermore, such failures might be predicted by Anderson and Bjork's (1994) account of a 'context bias' when target and non-target study contexts are not sufficiently distinct. Consistent with the above account, it is interesting that non-targets in the picture condition of Experiment 2 did not elicit a negative old/new effect – although this negativity was not quantified over the mid-parietal site in this experiment, there was no sign whatsoever that these items elicited the effect. Therefore, it can be surmised that, given their distinct modalities, target (words) and non-target (pictures) study contexts were distinct enough in Experiment 2 to allow the successful adoption of a retrieval orientation that led to the exclusive recollection of targets. It might be further assumed that, in the case of a failure to prevent the retrieval of non-target context, an assessment of the match between the information retrieved and that specified for the retrieval search would be required.

So far, it would seem that the above mechanism(s) could account for the pattern of left parietal old/new effects elicited by targets and non-targets in the series of experiments reported in this thesis. First, by adopting a specific retrieval orientation, retrieval attempts can be focused on target source information when memory for these items is good. This is successful when target and non-target study contexts are sufficiently distinct, causing a delay in the retrieval of non-target information. This scenario was apparent for the picture condition in Experiment 2 in which targets elicited a left parietal old/new effect during the 500-800 msec latency region, an effect that was not apparent for non-targets until 900 msec post-stimulus. However, non-target recollection would seem to have occurred too late to influence response decisions in this condition. In contrast, when there is considerable overlap between target and non-target study contexts, as was the case for the similar group in Experiment 4, it is not possible to focus retrieval attempts exclusively on target source information. This is consistent with the finding that, in Experiment 4, both targets and non-targets from the similar group elicited left parietal old/new effects during the 500-800 msec latency region.

However, when target and non-target study contexts partially overlap, retrieval attempts can be focused on the unique aspects of target source to prohibit the recollection of non-targets. This scenario concurs with findings for the different group in Experiment 4 of left parietal old/new effects during the 500-800 msec latency region for targets, but not for non-targets. This was qualified, however, by the observation that, during this latency region, while a left parietal old/new effect began to emerge for non-targets, a posterior negativity seemed to attenuate this effect from around 650 msec post-stimulus. Therefore, it would seem that the

recollection of these items could not be completely precluded. Unlike the delayed recollection of non-targets from the picture condition in Experiment 2, however, the emergence of non-target recollection from the different group in Experiment 4 would seem to have occurred early enough to potentially influence response decisions. Although the late posterior negativity was not quantified over the mid-parietal site in the earlier experiments, visual inspection of this effect suggests that this was also elicited by non-targets at around 650 msec post-stimulus in Experiments 1-2 for the word conditions only and in Experiment 3 for both the shallow and deep conditions. While left parietal old/new effects began to emerge for non-targets in the word condition of Experiment 2 as well as for those in the deep condition of Experiment 3, the posterior negativity, as described before, seemed to attenuate the left parietal effect from around 650 msec post-stimulus. So, again, the adoption of a specific retrieval orientation to focus retrieval attempts on target source does not seem to have completely precluded non-target recollection in these conditions. As is apparent from the pattern of results in Experiment 4, there does seem to be an attenuating effect of the late posterior negativity on the left parietal effect. However, left parietal effects were, nevertheless, reliably elicited by non-targets from the word condition in Experiment 1 as well as by those in the shallow condition of Experiment 3. Therefore, there would seem to be factors other than the modulating effect of the late negativity in determining whether or not reliable left parietal effects are obtained.

So, it appears that the apparent control over non-target recollection when memory for targets was good (and/or contextual information associated with targets and non-targets was sufficiently distinct) can probably be explained by the

operation of different types of retrieval strategies according to the modality correspondence between test cues and non-target memory representations. In the picture condition of Experiment 2, it would appear that a specific retrieval orientation allowed the processing of test words to selectively probe for episodic information relating to target words as opposed to non-target pictures. As apparent in other conditions, however, such specificity could not be obtained when non-target memory representations were also words. In this case, non-target information seemed to have, at the very least, begun to emerge. Instead, additional mechanisms would seem to be required to assess and possibly act upon mismatches between the targeted memory representation and the contextual details that were actually retrieved. The processes required to resolve such mismatches are thought to involve those that control general strategic and problem-solving operations and are not considered to be specifically dedicated to the memory domain (Burgess & Shallice, 1996). If the selective retrieval processing reflected in the pattern of left parietal effects discussed above is truly under strategic control, an 'attentional suppression' mechanism would seem to provide the best account of the data.

Future research

The above findings suggest a number of objectives for further research. First, given the observation that the magnitude of the late posterior negativity, particularly the early stimulus-locked component, seemed to correlate with the retrieval of contextual information that was considered *irrelevant* to the task demands, it will be of interest to further investigate this potential relationship. For example, the amount of irrelevant contextual information associated with targets and non-targets could be varied parametrically to see how tightly such information

correlates with the magnitude of this negative old/new effect. Non-target irrelevance and target salience might also be crossed factorially to see to what extent the effect of irrelevant contextual details on the elicitation of the negative old/new effect is dependent upon the successful adoption of a particular retrieval strategy. Following on from this, it will be important to check that the reliance on the retrieval of episodic information associated with targets, rather than non-targets, truly reflects a strategic control process. In other words, can selective retrieval processing be an explicit choice or is this implicitly influenced via the test instructions (Leynes, 2002)? So far, the data are equivocal with respect to this question. It seemed that the differential use of non-target recollection depending upon target salience reflected a strategic retrieval process. However, as target salience is actually confounded with target distinctiveness, selective retrieval processing may, in fact, be automatic and simply contingent upon the degree of similarity between target and non-target study contexts. Therefore, it may be informative to evaluate whether a similar pattern of effects may be obtained with explicit instructions to focus retrieval on a particular aspect of the study context (Dzulkifli & Wilding, 2005).

If it is found that selective retrieval processing is under strategic control, it will be important to further assess what type of mechanism can account for such strategies. For example, if it is hypothesised that inhibitory processes are being called upon it will be important to check the memory status of the items that have been apparently suppressed. As mentioned previously, retrieval inhibition in its strongest sense should affect accessibility at the *item* level (Anderson & Bjork, 1994). Free recall measures could be taken after completion of an exclusion task to

compare recall levels of non-targets across conditions for which differing levels of non-target suppression would have been expected to occur. For example, in Experiment 4 reported in this thesis, non-targets in the similar group, compared to those in the different group, should have sustained less suppression, given that these items were associated with fewer irrelevant contexts. However, any changes at the item level must be distinguished from changes at the level of associations and cues (Anderson & Bjork, 1994). In this case, it would be important to specify initial retrieval cues referring to, say, contexts that had been incidentally encoded and that were non-diagnostic of item status (i.e., targets vs. non-targets). Finally, it will be of great benefit to compare complementary data across ERP and fMRI studies using the same experimental paradigms to investigate both the anatomy and time course of brain activity associated with strategic and control processes in episodic memory retrieval.

Conclusions

The adoption of a specific retrieval orientation has been proposed to account for the finding that test words can be used to selectively retrieve episodic information involving target words as opposed to non-target pictures (Herron & Rugg, 2003b). The main question asked in this thesis was whether the same mechanism could account for the findings of strategic control over non-target recollection when targets, non-targets and test cues were words (Herron & Rugg, 2003a). Assuming that such control is strategic, based on findings from the experiments presented in this thesis, it is argued that the retrieval strategies permitting the exclusive retrieval of target source information in the two experiments are different. It seems quite likely that a mnemonic control process,

'retrieval orientation', was adopted to selectively probe memory for episodic information involving target words as opposed to non-target pictures. In contrast, when target and non-target study contexts are less distinct, a strategic control process, 'attentional suppression', would seem to provide an account of how target memories can be successfully isolated from among competing alternatives.

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